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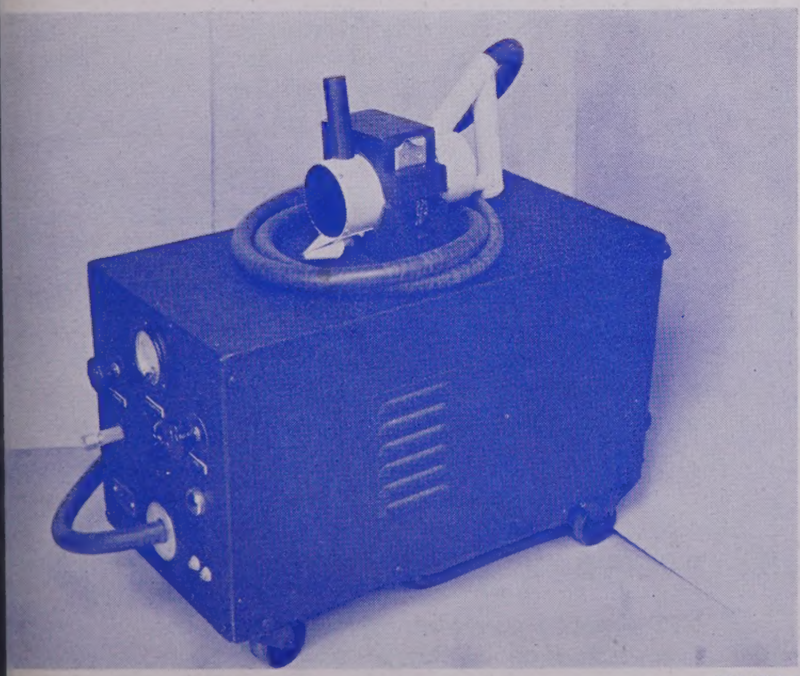

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AUGUST, 1945

Volume 33 Number 8

The Institute of Radio Engineers

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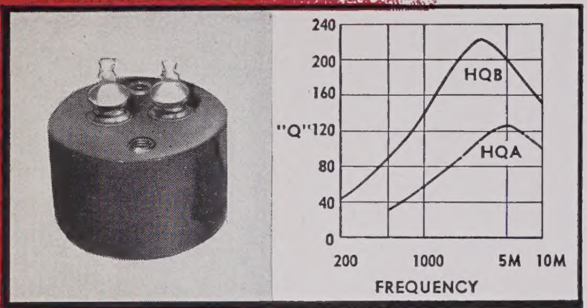

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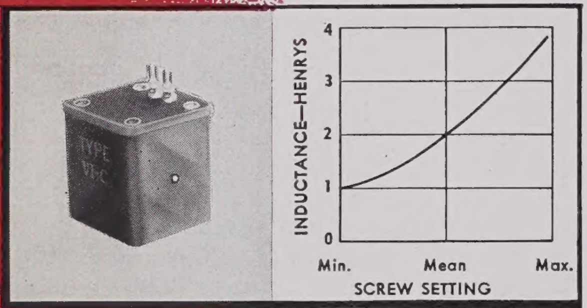

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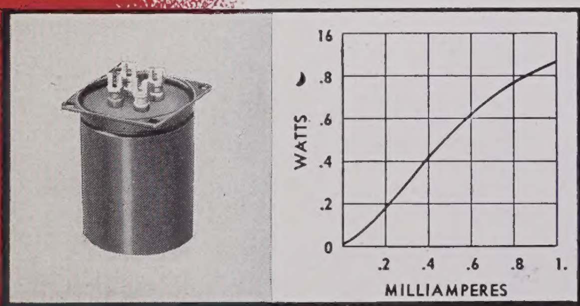

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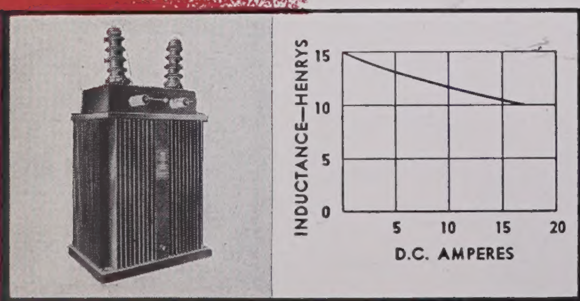

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THE INSTITUTE OF RADIO ENGINEERS

INCORPORATED

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CONNECTICUT VALLEY September 20	DAYTON September 20	DETROIT September 21	LOS ANGELES September 18	NEW YORK September 5
PHILADELPHIA September 6	PITTSBURGH September 10	PORTLAND September 10	WASHINGTON September 10	WILLIAMSPORT September 5

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The Sections of The Institute of Radio Engineers, taken together, *are* the Institute. Accordingly, whatever binds each Section more closely to the other Sections and to the directors, officers, and staff of the Institute is greatly to the benefit of every member of the Institute.

With this aim in view, the Chairmen of the Sections of the Institute have been invited to present their views to the entire membership through guest editorials appearing in the PROCEEDINGS. The following stimulating and encouraging statements by the Chairman of the Cleveland Section are here presented.

The Editor

The Sections and Institute Affairs

HUGH B. OKESON

The Institute of Radio Engineers accepted the challenge of war in 1941 and the records of the radio and electronics industries in the war are ample proof that the Institute and its membership have measured up to the challenge. The record is nothing short of phenomenal.

As the war has progressed it has become apparent that the Institute would progressively face new problems as the various phases of the war are won and we move on into the postwar period. These new tasks include measuring up to the new responsibilities, obligations, and opportunities of service to industry and the radio and electronics art, all resulting from the great achievements and expansion of that art during the war.

The Officers and Directors of the Institute are fully aware of the challenge the Institute faces. The vision and judgment shown in the steps that have already been taken in the Building-Fund Campaign to provide a National Headquarters and the other plans for expansion of the Institute activities are proof of this fact. We may be assured that Institute Affairs are being handled in an orderly and constructive manner. The stage is set for an impressive expansion of the Institute, possibly far beyond the expectations of some of the membership.

This brings us to the responsibilities and obligations of the Sections and the membership in general in this expansion program. I believe that we will agree that the Officers, Directors, and Management of the Institute are pointing out to us an adequate program for the future. It logically follows then that it is our obligation and opportunity as individuals to aid the new program in any way possible, in order that it may be brought to a successful conclusion. The Building-Fund Campaign is most encouragingly moving forward. Industry has responded in a splendid manner, showing appreciation of the service I.R.E. has put at the disposal of the radio and electronics industry. Membership can do no less, and I am sure that the membership-gifts quota will be oversubscribed if each individual will only ask himself how great his loss would be if I.R.E. were not here and functioning for his good.

At the present time a vote *for* the proposed amendment to increase the dues structure would appear to be a *must* for all of us in order that the proposed expanded services of the Institute may be made to function.

We also have an opportunity to increase our membership simply by presenting the facts concerning the real value of Institute membership to the vast number of qualified nonmembers waiting for this information. We must follow up these invitations and see that the membership applications are properly filled out and placed in the hands of the Membership Committee, or mailed to the Institute Secretary.

We may increase our benefits and those of the entire membership of I.R.E. by entering into expanded Section activities, attending meetings, working on Committees, and accepting elective office in the Sections and the Institute as these honors come to us. After we have done this for a short time, we shall be looking for new opportunities of service and not counting up how much we are getting out of I.R.E. The latter will take care of itself and our benefits will be many.

Let us all be more active in Section affairs than we have been in the past. By doing this, we shall be a factor in promoting the general interests of the Sections, The Institute of Radio Engineers, and the radio and electronics art.

Arthur Van Dyck

Commander A. F. Van Dyck was born on May 20, 1891, in New York State. During high-school and college years, he entered radio the hard, but the most interesting way, as an amateur. During vacations, he worked as wireless operator at sea, cruising to South America and England. He was graduated from the electrical engineering course at Yale University in 1911, and joined the National Electric Signalling Company (Fessenden) in research work at Brant Rock, Massachusetts. Upon the termination of that company's activities, he went to the research department of the Westinghouse Company, East Pittsburgh, for general development work, specializing in high-voltage, high-frequency problems.

From 1914 to 1917, Commander Van Dyck was an instructor in electrical engineering at the Carnegie Institute of Technology, a position which he left, upon our entry into World War I, in order to join the United States Navy as Expert Radio Aide. Then, as before World War II, the Navy had prepared for war, and the radio plans for World War I included the bringing in of civilian experts, of whom there were not so many in those days, to head technical work at the Navy Yards and Bureaus.

In 1919, he left the Navy to join the Marconi Wireless Telegraph Company of America, and was in charge of the factory engineering department of that company when it was absorbed in the formation of the Radio Corporation of America. For two years, he was in the Schenectady radio department of the General Electric Company, then the manufacturer of radio apparatus for RCA, and remained with that company in various capacities connected with its broadcast development and manufacturing activities until 1942, when he was called to active duty in the United States Naval Reserve, and was granted a leave of absence.

From 1930 to 1942, Commander Van Dyck was manager of the RCA license laboratory, which became widely known in the industry for its consultation service to radio companies, and for its output of useful developments. That laboratory has now become the industry service division of RCA Laboratories.

Commander Van Dyck is in the Office of the Chief of Naval Operations, Electronics Division, Washington, D. C., and has made several trips overseas in connection with electronic planning. He is a charter member of The Institute of Radio Engineers and has served on the Board of Directors from 1930 through 1935. He was President of the Institute in 1942.

The Interdepartment Radio Advisory Committee*

Its History, Mode of Operation, and Relationship to Other Agencies

E. M. WEBSTER†, FELLOW, I.R.E.

THE INTERDEPARTMENT Radio Advisory Committee, an organization of the Federal government, more commonly referred to as the IRAC, will have been in active continuous existence for 23 years this summer. It is composed of the representatives of twelve government agencies, their alternates, and a small secretariat. Five of these agencies are represented on the organization's technical subcommittee, its only standing committee. The IRAC came into existence June 1, 1922.

Under the law it is the responsibility of the President to assign frequencies to government stations, which he does periodically by means of Executive Orders. The IRAC, as his advisory agency, makes assignment recommendations for insertion in the Executive Order and by his authority makes interim assignments which are included when appropriate in the next Order. Stripped of its legalistic form, the function of the IRAC is, in actual practice, to assign frequencies to government radio stations, in which respect it bears much the same relation to government departments as the Federal Communications Commission to the nongovernment interests. In addition, it assists and advises the President and the various federal agencies on related technical radio problems of interagency interest, and on other questions as may be referred to the Committee from time to time by the President.

First official recognition of the authority of the IRAC in connection with allocations came about in 1927 when, in a letter to the Secretary of Commerce, the President justified the action of the Committee in assuming the responsibility for advising him in regard to frequency assignments for the government. This responsibility has come down unchanged to the present.

The IRAC is unique among government agencies in that it came into being, not as the result of action by either the executive or legislative branches of the government, but spontaneously through a demand of the interested government agencies. It has continued because it fills an essential need and because, throughout its existence, it has been careful to confine its activities to filling that need. In the process, it has furnished a conspicuous example of voluntary self-regulation resulting from a realization of the necessity for co-operation and co-ordination in the common good.

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† Captain, United States Coast Guard; Chairman (formerly Vice-Chairman), Interdepartment Radio Advisory Committee, Washington, D. C.

The First National Radio Conference, combining both government and industry representatives, was held in Washington in 1922 to discuss regulation and control of the fast-growing radio services. This conference awakened several of the government departments to the necessity for co-operative action in solving the problems arising from the federal government's interest in broadcasting, especially since the Navy Department had established broadcasting facilities at the Washington Navy Yard and made them available to other government departments. It was proposed that the Committee assist in regulating and guiding the operation of this station and any others that might be established by the government. At the suggestion of Dr. S. W. Stratton, Chairman of the conference, Secretary of Commerce Herbert Hoover, under whose department radio was regulated in these early days, invited interested government departments to designate representatives for a special government radio committee. The Secretary's invitation was answered by seven government departments, whose representatives first met in April, 1922. The genuineness of their interest may be judged by the fact that all seven, Agriculture, Commerce, Navy, Post Office, State, Treasury, and War, are still numbered among the twelve government agencies now represented on IRAC. The five added later are the Departments of Interior, Justice and Labor, the Federal Communications Commission, and the United States Maritime Commission. On April 17, 1922, the original seven representatives recommended that a permanent interdepartment committee be formed; their recommendation was approved and the first meeting of the new committee was held on June 1, 1922, with Dr. Stratton as chairman and Dr. J. H. Dellinger, who was to be continuously associated with IRAC from that date to the present, as secretary.

The name first taken by the new group was the "Interdepartment Advisory Committee on Government Radio Broadcasting." Despite the name originally chosen, it was apparent from the first to most of the members that their interests in radio would not be confined to broadcasting. At the first meeting, in fact, a proposal was submitted to extend the committee's scope to general radio communications. Within the year, this point of view became general and the name was changed to "Interdepartment Radio Advisory Committee" which name it still bears.

Less than two months after its formal creation, the committee found the field to which it was eventually to devote most of its efforts. The minutes of July 27,

1922, indicate a discussion with respect to the assignment of a wave length. Steadily from that time on, allocations occupied an increasing proportion of the committee's time, with interest rapidly diminishing in aspects of radio not closely allied.

To those interested in the early days of radio, the minutes of the IRAC are interesting reading. Some of the items have their amusing aspects, as for instance, the discussion at several of the first meetings on a proposal that the government install radio receivers in the public parks of Washington for the reception of Navy band concerts. Nothing came of it, it might be added, since the War Department, after trial, reported that the quality of the music was not sufficiently good to justify a permanent system. Since the matter was then referred to the technical subcommittee, we may assume that the poor quality involved the radio system and not the Navy's music.

Aside from such items, however, the minutes not only trace the growth of the entire field of radio communications but indicate IRAC's close contact with its problems. One of the earliest actions of the technical subcommittee was a recommendation that trials be conducted to determine the relative merits of tube versus arc transmitters. The same year, 1922, saw the opening moves that were later to culminate in the international radio conference held at Washington, in 1927; it was apparent to the government departments involved that the newly formed IRAC was an ideal body for the discussion of government problems in connection with such matters, and it was recommended that the technical subcommittee hold the necessary preparatory meetings.

The disposal of obsolete surplus government radio equipment is already looming as one of the major problems to follow World War II, just as it was after World War I. It is interesting to note that, after the previous war, it was the IRAC which, in 1925, requested the Navy and the United States Shipping Board to discontinue the sale of discarded spark transmitters so that interference from that type of equipment might be curbed. Today, the postwar problems posed by the impact on the spectrum of such surplus gear as walkie-talkies, with their unstable frequency characteristics, and certain electronic devices, with their wide bands of emission, will be a matter of deep concern to all of us.

All this seems so long ago as to have little connection with present-day radio. Yet, as early as 1928, the IRAC first took up the problem of frequency allocations for television and for the aeronautical service. The outgrowth of these studies with respect to television resulted in a recommendation by the late Federal Radio Commission that the service be given a 200-kilocycle band running from 2750 to 2950 kilocycles, exactly one thirtieth of the spectrum space now employed for a single television channel. Its studies in connection with aviation were prompted by a desire to bring about uniformity of aircraft communications and navigational aids, and to avoid duplication of stations and frequencies. The report pointed out that extensive use of radio for aviation had not yet materialized, but observed that when it did, the band of 35 kilocycles then available for this service would probably prove to be inadequate. Beginning in 1935, aviation needs assumed a prominent place on the IRAC agenda when the federal government began installing air navigation, air-ground, and point-to-point facilities on a large scale.

During the troubled period of the past few years, the IRAC's agenda has reflected the successive phases of national emergency and war. The years 1940 and 1941 show a steadily increasing number of applications from the Army and Navy, particularly for domestic aviation use. In 1942, there was a corresponding demand for overseas communications facilities. Still further expansion is noted in 1943, as the tide of war swung in our favor and larger land and sea areas were involved. The extent of the radio-communications facilities required by our operations in Europe and the Pacific is almost beyond comprehension. The resultant situation was responsible, in 1943, for a significant landmark in the field of frequency allocations. In that year, an important agency of the United States Government found its request for radio facilities denied in part by IRAC because of the impossibility of finding sufficient usable frequencies. Since then, the expanding requirements of radio communications have been met with progressively greater difficulty, and then only by acceptance of increasing amounts of interference on the part of existing services.

To speak of present-day frequency allocations touches on a situation that few anticipated. That is, that as a practical matter, the government does not have unlimited use of the spectrum in time of war. To many, this will be hard to believe. After all, it has been accepted as axiomatic that all radio facilities become available to the government in an emergency, and even the communications act so provides. Even in the IRAC, as late as 1928, we find this assumption reflected when a proposal for special wartime military assignments was objected to as unnecessary in view of the availability of the entire spectrum to the government in time of war. Theoretically, it may be; actually, it is not. War today is not a matter of armies and navies alone; it involves all the people. Radio is necessarily associated with many other aspects of the war effort than the purely military. We could not suspend domestic broadcasting; we have found it necessary not only to continue international broadcasting but to augment it; our airlines must continue to operate, and their complex and extensive network of communications and airport control facilities are essential to their operation; navigational aids for both air and marine use have to be maintained; point-to-point circuits to our allies and to neutral nations cannot be appreciably curtailed; our municipal and state police radio systems must continue; the radio facilities required for the protection of our forests have to be kept in operation. Of course, a number of frequencies were

nevertheless made available by the point-to-point, coastal, and amateur interests. It is perhaps appropriate at this point to acknowledge this co-operation of the amateurs in relinquishing their bands, and of the commercial interests in rearranging their services and accepting interference which in normal times would be considered intolerable.

Early in 1943, the IRAC realized that the end of the war would bring with it a tremendous demand for frequencies, not only from the activities which have been curtailed during the war, but from enormously expanded commercial aviation and new activities. It was obvious, too, that the military establishment would not shrink to its prewar level. Accordingly, the IRAC appointed a special subcommittee to consider postwar frequency allocations. During the subsequent ten-months' study by this committee, many radio experts of the industry were called in for private informal meetings in order that the members of IRAC would have the benefit of their knowledge. Finally, under date of June 15, 1944, the committee issued its now well-known proposals for postwar spectrum allocations.

It may be asked why the IRAC, spokesman only for government needs, presumed to propose a general allocations table. Part of the answer is found in the fact that international allocations do not differentiate between government and nongovernment, so that any plan must eventually assume the shape of a general allocations table. Further, the postwar allocations problem below 25 megacycles represents mainly a matter of adjustment to accommodate increased navigation aids, permanent military establishments, and aviation. The first two are government subjects, while the third finds its counterpart in our wartime military air transport services. Above 25 megacycles, certain allocation landmarks exist in the shape of vast quantities of equipment in world-wide use, much of which will find commercial postwar use. No one can seriously hope to draft an allocation table for this region without full knowledge of these landmarks. At the moment that knowledge is confined largely to the government and is subject to security restrictions. The IRAC indicated these landmarks, and also insisted that the amateur bands be placed where they would be useful for wartime military expansion, but beyond that, suggested only a division of spectrum space between government and nongovernment.

It may be added that currently the IRAC is modifying its original proposals as a result of continued discussions with the Federal Communications Commission, taking into account the Commission's findings resulting from its recent hearing "In the Martter of the Allocation of Frequencies to the Various Classes of Nongovernment Services in the Radio Spectrum from 10 kilocycles to 30,000,000 kilocycles."

Relation of IRAC to Other Agencies

The IRAC's authority to allocate frequencies to government radio stations makes it an important body; it is worth while to examine carefully its relation to other agencies.

It is desirable from the start not to confuse IRAC with other agencies. This frequently occurs. The specialized nature of frequency allocations work requires that such matters within each agency be centralized in a small group, usually only one or two individuals. These people represent their respective agencies whenever frequencies are involved, but it should be emphasized that, while each is acting to some extent as an individual, he is primarily the medium of policy expression for his organization. At times there may be several committees working on frequency allocation matters, particularly when, as at present, preparations for telecommunications conferences are in progress. Regardless of the number of committees, the people on them are for the most part the same, thereby insuring continuity and co-ordination.

The agency with which the IRAC is perhaps most closely associated is the Federal Communications Commission. As previously indicated, the IRAC assigns frequencies to government stations while the FCC assigns frequencies to nongovernment radio stations. However, while the scope of their operations can be clearly distinguished, their activities cannot be wholly separated, since the assignment of any frequency may affect the users of other frequencies. Separate agencies such as IRAC and FCC, therefore, cannot both allocate frequencies without complete co-ordination. In this instance, the co-ordination is very simply achieved: the FCC is one of the members of the IRAC. To summarize the relations of IRAC and FCC: they are independent bodies, having equal authority to make frequency assignments in their respective fields, and they co-ordinate their day-to-day activities through the medium of FCC's membership on IRAC.

After the outbreak of war in Europe, the President created the Defense Communications Board, now the Board of War Communications. It was given broad powers of policy-making nature with respect to the placement of United States communication facilities on a war footing. The IRAC was designated as Committee V of the Board to advise on frequency matters involving government radio stations. Thus, the IRAC has direct connection with the Board of War Communications, as a committee of that Board. However, it is important to keep clearly in mind that the IRAC still carries on certain activities separate and distinct from its function as Committee V of the Board of War Communications, particularly with respect to postwar matters. This dual nature was emphasized last summer when the IRAC, acting as such and not as a committee of the Board, prepared its postwar frequency allocation plan. This plan was forwarded by IRAC direct to the Department of State, the agency charged with the responsibility of preparing United States proposals for international telecommunications conferences. In this connection, care should be taken not to confuse the IRAC with special

committees created by the Department of State from time to time to centralize such preparations.

With its extensive records and the increasing complexity and volume of the minutes of its meetings, the IRAC maintains a modest permanent secretariat. In 1928, the subject of funds for an IRAC secretariat was discussed, but it appeared that the small sum involved did not warrant a separate appropriation by Congress. It has been found more practicable for the FCC to include funds for the purpose in its own budget and to furnish office space. Under this arrangement, it is logical for the FCC representative or alternate to be elected as the secretary of the IRAC. This physical connection between the FCC and the IRAC secretariat is a matter of convenience, inasmuch as the records of both agencies are thus centralized, and readily available to each other.

Organization

The organization of the Committee follows a rather simple form: a chairman, a vice-chairman, a secretary, and one standing committee; i.e., the technical subcommittee, with its chairman. Special subcommittees are appointed when required for specific purposes.

The method of selection of the chairman and vice-chairman may be of interest, as it solves the frequently recurring problem of equality of opportunity and recognition. Both officers automatically take office in alphabetical order of the member agencies for a term of one year, except that any member agency has the option of declining, in which event the office is automatically offered to the next member agency in alphabetical order. Currently, the Navy Department holds the chairmanship, and as the result of the declinations of both the Post Office and State Departments, the next in alphabetical order, the Treasury Department, holds the vice-chairmanship.

The secretary is elected by the Committee for a term of two years, and must be a representative or alternate of one of the member agencies.

The technical subcommittee, whose chairman is elected by the IRAC for a two-year term, considers specific technical problems assigned to it by the main committee.

The regularity of IRAC meetings is not only required from the point of view of the importance of the mission of the Committee, but is necessary to the expeditious accomplishment of its work. Meetings are held on the first Thursday of each month, with ten meetings a year specified as a minimum. Special meetings are held at the call of the chairman. Parliamentary procedure governs the conduct of meetings, a majority constitutes a quorum, and all members and alternates may participate in debate or call upon technical assistants to present information.

The value of any committee rests not only upon the soundness and wisdom of its decisions but upon the processes of arriving at those decisions. The importance of the latter was considered so vital that the IRAC provided in its by-laws that the Committee shall endeavor to reach unanimous agreement on all questions discussed. However, upon request of any member agency a record vote may be taken. Each member agency has but one vote, no proxies are permitted, and motions and elections are carried by majority vote. The IRAC is proud of its record in carrying out these democratic principles.

To those who have had experience in the complicated problems of frequency allocations, it is understandable that it would be impossible to make assignments which are just, fair, and equitable to all concerned without a mutually satisfactory set of principles. The present principles governing the assignment and use of radio frequencies by the IRAC are the culmination of over twenty years of molding and are so fundamental and important that they should be mentioned with some exactness.

Applications by a government agency for authority to use a radio frequency must be justifiable under reasons such as the following: specific legislative directives; international commitments, such as treaty obligations; national-defense requirements; protection of national resources; safety services; essential mobile communications; emergency communications affecting safety of life or property; research and experimental services; absence, inadequacy, or impracticability of establishment or use of other means of communication.

Recognizing that the demand for radio frequencies greatly exceeds the supply, and to make the most efficient and orderly use of the spectrum in the national interest, action by the IRAC is predicated on consideration of all available data, including international regulations, national laws, established government policies, national interest, availability of other possible communication facilities, and technical aspects.

The Committee examines the data submitted in the light of good engineering practice for conformity with respect to frequency and geographical separation, and endeavors to insure that the frequency selected, insofar as possible, is one having transmission characteristics best suited to the proposed use; that national and international allocation plans are recognized; that the frequency stability is the best which the state of the art and service requirements permit; that minimum power consistent with satisfactory performance is employed; and that the frequency band width of emission is the most restricted consistent with satisfactory communication. Assignments are made with due engineering consideration of the probabilities of adjacent channel interference, and after careful study of the possible effect of the assignment on frequency assignments and uses. If an assignment is made where there is a possibility of interference, appropriate restrictions are placed on the assignment.

The extensive sharing of frequencies between agencies together with ever-smaller frequency separations have

required IRAC to develop an intricate system of priorities which, because of its timeliness and possible future application in other jurisdictions, warrants examination.

The Committee defines priority as the right to occupy a specified frequency for authorized uses, free of harmful interference from stations of other agencies; in questions involving precedence in the use of radio-frequency assignments, the term indicates the superior rights of one agency over another. It depends upon considerations such as:

(a) Agreements and records, as set forth in national laws, Executive Orders, IRAC minutes and records, international and interagency agreements;

(b) National interest, wherein consideration is given to relative need for the frequency in question and to the degree of utilization by the agencies involved;

(c) Necessity for using radio, taking into consideration the availability of other means of communication;

(d) Expansion. Here, in the interest of planned and orderly utilization of the radio spectrum, the Committee recognizes the desirability of providing for normal expansion of a service where it is shown by the applicant that expansion will occur, and where its trend and magnitude can be estimated;

(e) Geographical priority, which, as applied to mobile stations, is construed to extend only to the geographical area specified at the time the frequency was assigned; as applied to a fixed station, it extends only to the geographical location of the points of communication designated in the authorization;

(f) Dates of assignment and first use, where other considerations are substantially equal, establish the priority as between stations unless by the terms of an agreement it is specifically provided otherwise.

To the end that there be most efficient utilization of the radio spectrum, acceptance of a radio-frequency assignment imposes definite obligations on the assignee with respect both to equipment and to use. Some of these are specified in treaties and laws. Among the important obligations are:

(a) To use the best and most selective radio apparatus the state of the art and service operating requirements permit;

(b) To use frequencies economically by avoiding unnecessary emissions and conducting operations on a minimum number of frequencies;

(c) To share frequencies between agencies as a recognized and necessary expedient for the fullest utilization of the radio spectrum.

You have now been told something regarding the history of the IRAC, its relationship to other agencies, its internal organization, and the principles it follows in the conduct of its work. We are proud of that history and of our harmonious relations with other agencies, and we believe that our organization is both businesslike and democratic. We feel this is the way in which you, as engineers, would wish to have us operate.

Some Aids to Facilitate the Engineer's Academic Training*

B. DUDLEY†, SENIOR MEMBER, I.R.E.

Summary—**The rapidly increasing complexity of radio engineering practice and the employment of very-high frequencies necessitates more thorough and intensive training of radio-engineering students. Greater facility in mathematics will be required, but should be accompanied by adequate correlation between the mathematics and the physics of the problem. The use of animated motion-picture films, working models, or static models and diagrams suitable for textbook use, are discussed as one means of improving educational methods.**

Introduction

As a RESULT of the technical developments which the war has accelerated, and the exposure of large groups of men to at least the elements of engineering thinking and training, some rather important revisions of engineering education may be required in the postwar period. This appears especially true in communication engineering as a result of vastly expanded techniques and the need for a more general and fundamental educational approach. It is certainly now necessary to teach radio-engineering students the fundamentals of nonsinusoidal recurrent and transient phenomena. It is necessary to develop concepts of the electromagnetic field in three spatial dimensions as well as of time, and to replace the simpler and more familiar circuit concepts in which time variations of voltage and current alone were sufficient to specify the behavior of communication equipment.

If the engineering profession is to maintain a high standard of excellence, the increased scope of engineering topics which it seems desirable to teach must lead, it would seem, to one or both of the following procedures: (1) More effective and powerful teaching

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methods must be employed to provide the student with a sound foundation of generalized engineering principles; and (2) the length of training required for professional proficiency must be increased.

Need for More Mathematics

Undoubtedly there are many opportunities for increasing the effectiveness of teaching methods, particularly in mathematical subjects. Science and engineering are based on quantitative relationships which can best be expressed through the employment of mathematics. While the simpler problems can be treated adequately with the simpler branches of mathematics, radio-communication engineering is now sufficiently complex that, as minimum professional requirements in mathematics, every electrical-engineering graduate should possess facility in the setting up, solution, and use of linear partial-differential equations. He should be able to "think" in terms of three-dimensional time-varying quantities.

Consequently, a greater and more effective training in mathematics for undergraduate engineering students appears to be imperative. In contrast with the mathematician, the engineer is interested in mathematics as a useful working tool. His mathematics is applied mathematics. Every term, every coefficient, every exponent in his equation must, of necessity, have physical significance. Such mathematics becomes and should represent very much more than a mere "crank-turning" process. It is, in fact, a concise, compact method of quantitative thinking, and expresses the physical relations between those engineering quantities in which the engineer is vitally interested. Therefore, the physical interpretation of mathematics should be particularly emphasized. Textbook authors can aid by dissecting the important equations indicating those portions of the equation which represent amplitude, frequency, phase, initial and reflected components, and the like.

Methods of Obtaining More Effective Interpretation

Undoubtedly much more than has already been achieved can be accomplished in the physical interpretation of mathematics, through the judicious use of animated motion pictures, models, and more effective textbook illustrations. For example, the fundamental processes of modulation and detection, or of radiation of electromagnetic waves, are complicated operations, frequently requiring a sizable sprinkling of mathematics for a proper elucidation. But, if these topics were illustrated by means of accurately drawn and correctly produced animated drawings, and these drawings were, in turn, properly co-ordinatedwith the mathematics of the problem they represent, no electrical-engineering student could fail to grasp the fundamental problem the first time he was exposed to the topic.

As an indication of what could be achieved in this direction, imagine a Walt Disney creation, executed somewhat in the manner of "Fantasia," but in which there are portrayed accurately the correlation between the mathematical and physical interpretation of problems which students do not perceive readily. How quickly the student's grasp of fundamentals could be improved if such a method were applied to topics such as the production of beats, the behavior of nonlinear amplifiers having reactive loads, the fundamentals of amplitude- or frequency- and phase-modulation, the establishment of the electromagnetic field by a radiating system, or the transient behavior of networks!

In industrial electronics, these films might deal with timing, differentiating, integrating, or clipping circuits, but the real opportunity lies in the elucidation of field phenomena or mathematical concepts which can be represented in three-dimensional space.

Requirements for Films on Engineering Principles

Of course, such an invigorating film must extend considerably beyond those films, produced at about the trade-school level, whose primary objective has been the picturization of qualitative relations. The complete and precise correlation between the mathematics and the physics of the problem is the essential element of the desirable engineering-educational film.

We can hardly afford to overlook the economic factors in producing films such as those suggested. The potential audience will be, numerically, relatively small, and the cost of the animated films will be high. Therefore, it will probably be necessary to produce a relatively small number of films on different topics, and to distribute these as widely as possible. This procedure, in turn, would necessitate a certain amount of standardization in courses in communication and electronics. The Institute of Radio Engineers might well take the lead in making concrete suggestions in this direction.

Animated motion-picture films are not the only means of clarifying an understanding of fundamentals. For example, working models, in motion, a series of static three-dimensional models, or, failing these, a group of three-dimensional drawings in some form of perspective will help make clear the spatial relationship encountered in field problems. Such drawings or models can be made of inestimable aid in teaching a subject as complicated as radio engineering. To a very limited extent, three-dimensional drawings have begun to be employed in the treatment of wave guides, and the use of such diagrams is to be commended.

However, such diagrams should not be restricted to wave guides or to radiation problems. They lend themselves admirably to any problems in which a family of curves connecting three variables may be used to represent quantitative relationships.

Perspective Representation for Resonant Circuit

Consider, for example, the behavior of a simple series circuit, composed of linear-lumped elements of R, L, and C and energized by a voltage source E of variable

frequency. It has been customary to graph the variations of capacitive and inductive reactances as a function of frequency, and by algebraic addition of these two curves to show the absolute value of the net reactance as a sort of V-shaped diagram. The resistance component cannot properly be included on such a diagram,

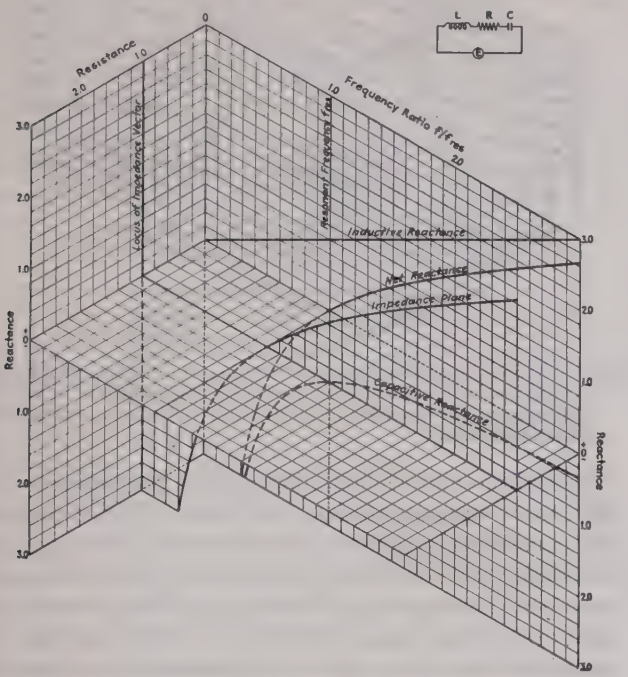

Fig. 1—Isometric drawing showing the relations between reactance, resistance, impedance, and frequency for single series R, L, C circuit, constant resistance.

even though a separate set of ordinates may be provided for its inclusion. If it is desired to show the vector relations of such a circuit, a completely new and separate diagram is required. Yet all of these data, and more, can be shown quite easily by a three-dimensional drawing as shown in Fig. 1. For several years, such a diagram has been used in teaching classes in radio engineering, with very satisfactory results. The construction of such a drawing, while readily apparent, nevertheless does not seem to have received attention previously.

In Fig. 1 we have three separate planes, each of which represents a certain physical concept. The vertical frequency-reactance plane at the right represents the circuit reactance, while the vertical resistance-reactance plane represents the vector relations of the circuit. It will be noted that the resistance-frequency plane has been shown horizontal and at 90 degrees to the reactance-frequency plane, as required by the familiar j notation and vector diagrams. Furthermore, both the resistance and the reactance components are properly shown as depending upon frequency.

By looking to the right at the reactance-frequency plane, the net reactance of the circuit, as well as that of its components, is readily determined for any frequency. By looking down on the resistance-frequency plane, the circuit resistance represented by the real term in circuit equations is evident. Finally, by looking at the resistance-reactance plane, giving the vector relations for the circuit, as by viewing from outside of the model from the extreme left, we see the locus of the impedance vector as a straight line, since the circuit resistance is assumed to be constant and independent of frequency in this case.

All of these quantities are correlated in the impedance plane which shows that at low frequencies the impedance vector is large and negative, becoming a minimum, equal to the resistance of the circuit, at the resonant frequency, and then increasing to larger and positive value as the frequency is increased beyond resonance.

If, as is known to be the case, the circuit resistance varies with frequency, this can be shown easily in the three-dimensional drawing. For the usual case, the resistance is proportional to the square root of the frequency. The impedance plane now becomes somewhat curved and the locus of the impedance vector is a sloping and slightly curved line on the resistance-reactance plane.

Other Examples of Three-Dimensional Drawings

We may employ the same general type of drawing to represent the behavior of a parallel or antiresonant circuit, as in Fig. 2. This illustration shows the behavior of the usual type of antiresonant circuit in which the series resistance in the capacitive arm is assumed to

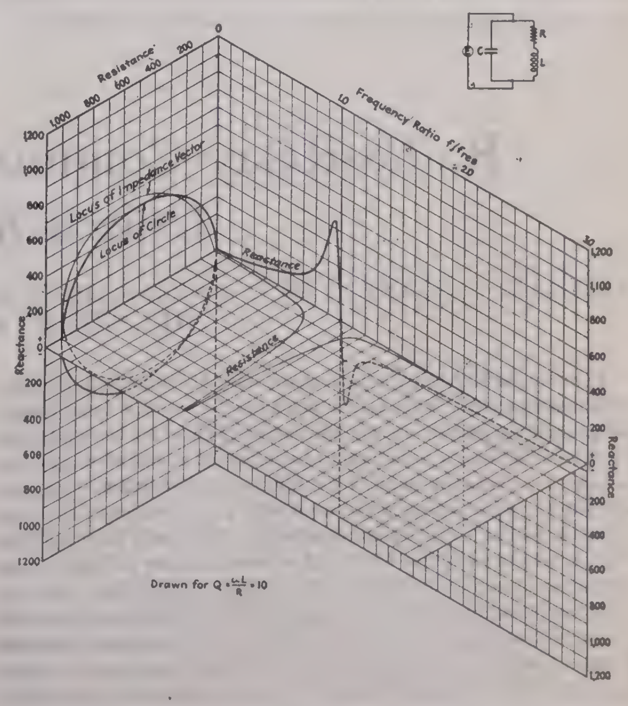

Fig. 2—Isometric drawing giving reactive and resistive components of impedance of parallel R, L, C circuit. The impedance plane has not been drawn, since it would obstruct important portions of the diagram.

be zero, and in which the coil is represented by an ideal inductor in series with a fixed resistor. In this case the coil resistance has been assumed to be constant, but only a very slight modification of this diagrammatic model would be obtained for a coil whose resistance varies as the square root of the frequency.

To illustrate some of the points which such a drawing brings out, the drawing is plotted for a coil having the rather low Q of 10. Careful study of this diagram will show the two different resonant frequencies, one for zero net reactance, and one for which the capacitive and inductive reactances are equal. The diagram has been drawn for the latter case. The diagram also shows that, in the case of the low-Q coils, the locus of the impedance vector may differ quite appreciably from that of a circle which is usually considered to apply for parallel-resonant circuits. In this drawing the impedance plane has not been included since it would obstruct important parts of the diagram; only the resistive and reactive components appear.

The concept of such three-dimensional diagrams may be applied to vacuum-tube characteristics, as in Fig. 3. On such a diagram it is possible, as shown here, to designate the operating limits of the tube, as given by the tube manufacturer. It is also possible to indicate graphically all of the variational parameters of the electrode circuit for which the diagram applies. Usually, as in this case, the plate characteristics are given, and consequently the amplification factor, internal plate resistance, and transconductance are derivable. However, three-dimensional diagrams of grid characteristics have also been plotted from which the equivalent variational parameters for the grid circuit may be determined.

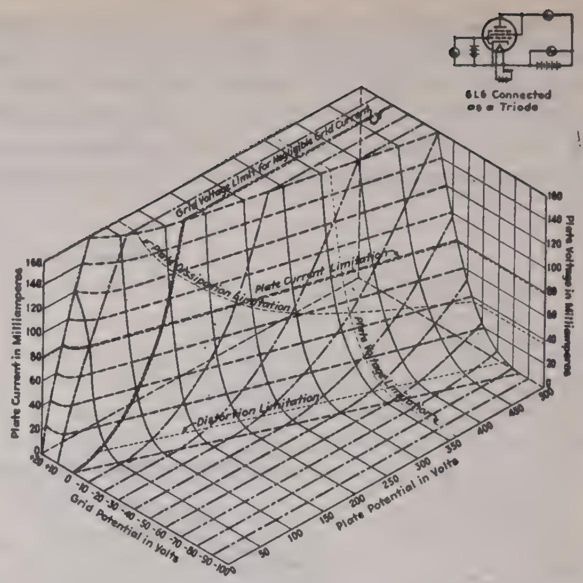

Fig. 3—Three-dimensional perspective diagram of plate characteristics of triode. Limits of amplifier operation indicated. The relations shown are intended to be used for educational rather than design purposes.

Such three-dimensional diagrams are, of course, somewhat more difficult to draw and require more time for this construction than the usual plane representations. However, they convey very much more information and show the essential and fundamental relationships so very much more clearly than is possible with the old techniques that they have very definite advantages for educational purposes. Such drawings lend themselves to reproduction on the printed page. For laboratory or classroom instruction, suitable models might be constructed of lucite sheet or plaster of Paris.

Radio-Relay Communication Systems in the United States Army*

WILLIAM S. MARKS, JR.†, SENIOR MEMBER, I.R.E., OLIVER D. PERKINS†, SENIOR MEMBER, I.R.E. AND WILLARD R. CLARK†, MEMBER, I.R.E.

Summary—This paper describes the use of frequency-modulated, very-high-frequency radio sets in place of wire lines in Army tactical communication circuits. During the early phases of the war and pending development and production of equipment designed to meet requirements, standard police-type frequency-modulation sets were adapted for use. These were used with great success during the Tunisian, Sicilian, and Italian campaigns. Principally they provided simplex teletype circuits from higher headquarters to lower units. By the use of radio-repeater or relay stations these circuits were extended several hundred miles. Representative circuits are shown illustrative of employment, distances covered, and antenna elevations. A broad-band frequency-modulated very-high-frequency set designated AN/TRC-1 was developed for use in conjunction with voice-frequency-carrier equipment CF-1 and CF-2 to provide multichannel voice and teletype circuits over a single radio frequency. This has met with great success and was a most important communication factor in the Normandy invasion and battle of France. It marks the first real marriage of wire and radio communications in the Army and provides an integrated communication system. The advantages of a radio system over conventional wire lines under certain conditions are pointed out, such as a saving in men and material, establishment and maintenance of communications in a fast-moving situation, use over water, enemy territory, and rugged or mountainous terrain. Expanding and wider application of the principle is indicated.

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I. Introduction

Before describing the Army's very-high-frequency radio-relay system and the several representative applications made of it in actual

operations, it is well to take a brief look at military communications in general and review some of the problems and experiences which have influenced the development and increasing use of radio-relay equipment, thus making it possible to remove radio communications from their usual separate and isolated nets and place them together with wire circuits in a single communication system.

It has been said many times that this is a war of machines. One can well believe this when production figures are given for the thousands of airplanes, tanks, tank destroyers, trucks, heavy guns, and many other like items required to carry on this global war. It requires little imagination on the part of the communication engineer to envision the tremendously increased importance placed upon communications to co-ordinate the use of these high-speed weapons of war, and thus make their effective utilization possible. From the infantry soldier in the foxhole, from the commander in the tank, and from the pilot in the airplane to headquarters in Washington, there lies a vast and intricate communications network.

Fig. 1 gives some idea how military communications work. As indicated therein, the two means of transmission for these communications are wire and radio. Since World War I, the Army has always considered wire to be the primary means of communication, and radio the emergency means. This is still the basic policy of the Army, although the very nature of this war has placed ever-increasing emphasis on radio in many cases as the primary means. In fact, in this war, radio is the only means by which highly mobile elements, such as aircraft, tanks, amphibious vehicles, and assault troops can be controlled or co-ordinated effectively. It is the only means of communication across enemy-held territory, over water and terrain inaccessible for wire-line construction. This fact was well demonstrated during the Allied invasion of Normandy, General Patton's 3rd Army dash across France, and during General MacArthur's many amphibious operations in returning to the Philippines. More emphasis has also been placed on radio as an emergency means, due to the greatly increased hazards to wire from enemy bombs, shells, sabotage, and from friendly vehicular traffic.

The vital importance of radio communication poses a serious challenge to this nation to pioneer new fields of application and to design and produce equipment that will give superior performance in the hands of our fighting men. The Signal Corps Ground Signal Agency, through its various laboratories at Fort Monmouth, New Jersey, is responsible for the development of ground-radio equipment for combat troops of the Army and has been fully conscious of this challenge. That it has been well met is attested to in the many reports received from responsible field commanders citing superior performance of Signal Corps equipment.

This superiority is attributed in large measure to the extensive use of frequency-modulation equipment in the frequency band of 20 to 100 megacycles. In fact, all radio-communication equipment used in this band by the Army ground forces, representing a large proportion of their total complement of equipment, is exclusively frequency modulated. Those familiar with the amount of interference that existed in prewar-radio amateur bands have observed a small sample of the interference problem in the high-frequency band below 20 megacycles that exists in a combat zone. The removal from this band of many thousands of tactical radio sets was a major contribution to the efficiency of military communications.

Exploitation of this very-high-frequency band for ground-radio communication, and the adoption of a comprehensive line of frequency-modulation tactical radio sets, is due principally to the early pioneering and vision of Signal Corps officers and engineers at the Signal Corps laboratories under the direction of Major-General Roger B. Colton (then Colonel), and to the several radio manufacturers who assisted in the early frequency-modulation-development program.

There are two good reasons why the Army relies on wire as the primary means of communication. First, it brings to the ordinary user in the Army the same type of operation and service he has always been accustomed to in his home and business life, so that it has the very real advantage of familiarity. Second, it is considered inherently more secure. Therefore, if radio is to compete with wire, regardless of any tactical or economical advantages it may have, it must provide the same services equally well. The question of security is a problem all its own and will not be discussed here. This discussion will be confined to the problem of providing the Army with the familiar telephone, telegraph, teletype, and facsimile communication facilities by means of radio circuits instead of the conventional wire-line circuits.

In solving this problem the goal of the Signal Corps, and more particularly the Signal Corps Ground Signal Agency, has been to provide the Army with an integrated communication system, where, in the words of one Army Signal officer, "we have a marriage of wire and radio." Although integrated radio-and-wire communication systems of various types have been satisfactorily employed on a commercial basis for several years, the design and operating features of these systems are vastly different from those required to satisfy the tactical requirements for military systems. For example, the commercial systems are normally designed to operate in a fixed-plant type of installation under carefully controlled operating conditions, whereas military systems must incorporate certain peculiar features essential to flexibility of tactical employment in the combat zone, and still retain features essential to reliable operation as a fixed type of installation in the communication zone, pending the establishment of permanent wire-line facilities.

In the light of early experience in the successful development of tactical ground-radio equipment, it was

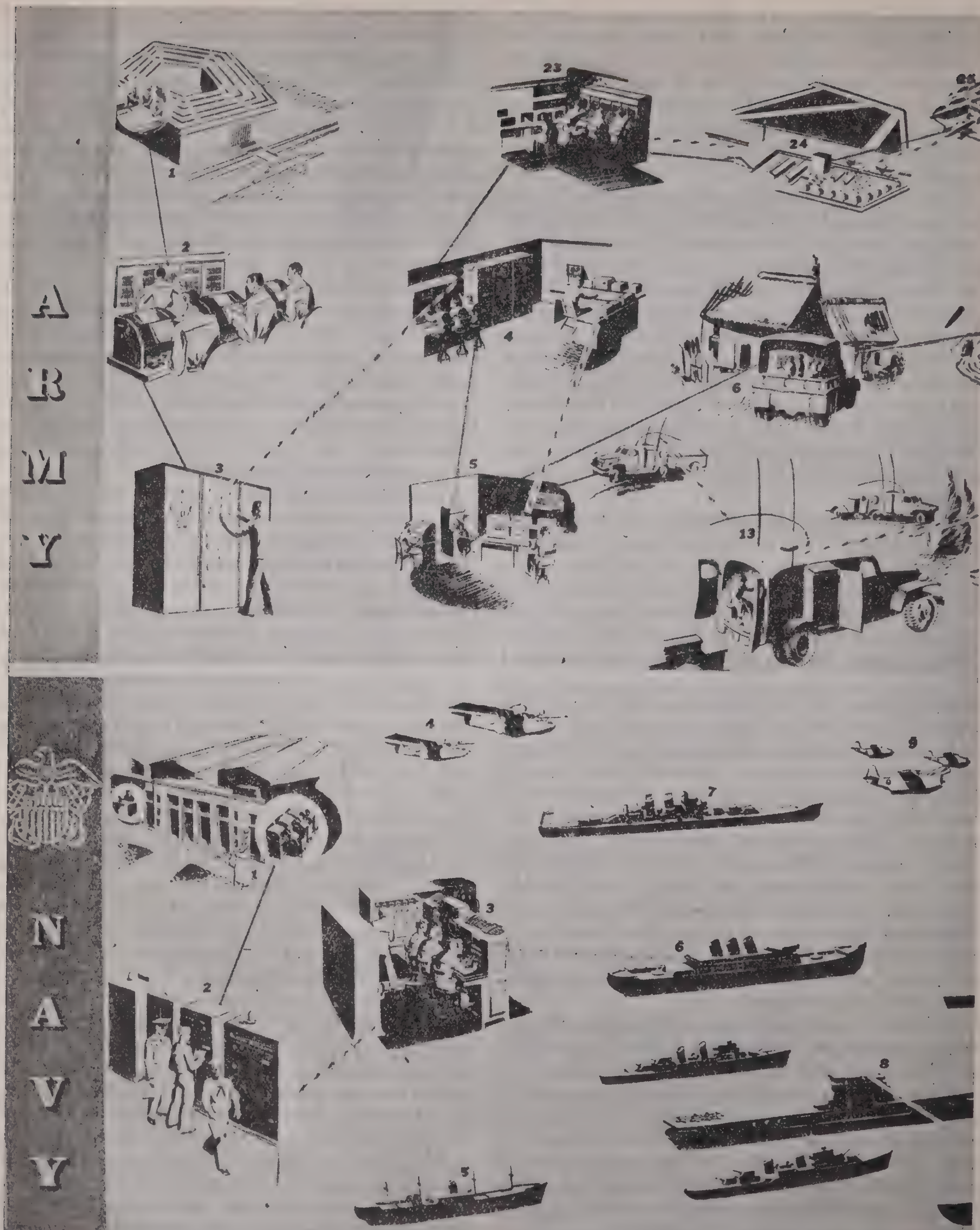

Fig. 1—How military communications work.

(Courtesy Western Electric Company)

recognized that the use of frequency modulation in the very-high-frequency band would permit the design of equipment well-adapted to integration with the wire-communication systems. Accordingly, development of a very-high-frequency broad-band frequency-modulation radio set, designated radio set AN/TRC-1, was initiated by the Signal Corps in the latter part of 1942. Work associated with this development was carried on at Coles Signal Laboratory. The Link Radio Corporation collaborated in the development and manufactured the first production sets.

II. Description of the Communication Systems

Those familiar with the design and development of military radio equipment can readily understand why ultimate design of such equipment must always represent a compromise between desired characteristics and practical performance characteristics which satisfy the governing military requirements. In the development of very-high-frequency radio-relay communication equipment for the United States Army, the following requirements were considered basic:

1. The radio equipment must be designed to operate in conjunction with existing standard wire equipment, in a manner which will provide for complete integration of the radio and wire systems into a single tactical communication system. Since the related wire systems included field-wire lines of moderate length, as well as cable lines capable of extending carrier-telephone facilities over distances in excess of 100 miles, this requirement indicated the need for a "single-channel" system, to operate over moderate distances, and a "multichannel" system, to provide for multiplex radio transmission of the carrier-telephone facilites over extended distances.

2. The operating frequency band used must be satisfactory for reliable day and night communication, relatively free of interference, and consistent with the provision of reasonably compact and easily erected directional-antenna systems.

3. Since the communication facilities are to be used by highly mobile organizations in the field, each complete system must be adapted to rapid assembly, installation, disassembly, and transportation in cargo aircraft to all parts of the world, and in small vehicles over rough terrain. In some cases, particularly in jungle or mountainous terrain, it may be necessary to man-pack the radio equipment over certain distances, in order to take advantage of the increased communication range obtained from selected sites having a high elevation above surrounding terrain. This required that the equipment be designed to operate satisfactorily in any climate of the world, withstand rough handling, and that size and weight of individual components be held to a minimum.

4. The equipment must be well adapted to installation, operation, and maintenance by a small number of military personnel having a minimum amount of specialized training.

The single-channel system is used in a more or less conventional manner as a general-purpose facility to supplement wire lines of moderate length. In its simplest form, it consists of two radio sets AN/TRC-1 installed at selected sites in the field and operated directly from the transmitter by means of an associated telephone handset. When the distance between the two operating sites exceeds line-of-sight, an additional radio set is installed at a suitable intermediate point and arranged automatically to retransmit signals received from either one of the terminal stations. A perspective view of this latter arrangement, with control facilities at the terminal stations extended over a wire line by means of auxiliary remote-control equipment, is shown in Fig. 2. Operation of the system is described as follows:

1. The radio receiver at each terminal station is tuned to frequency F_1 and the receiver at the relay station is tuned to frequency F_2. All radio receivers are connected to their associated radio transmitters by means of an interconnecting control cord and all panel controls are arranged for single-channel operation.

2. The radio transmitter at each terminal station is tuned to frequency F_2 and the transmitter at the relay station is tuned to frequency F_1. By appropriate adjustment of panel controls on the radio set at the relay station, circuit arrangements are made whereby the radio-frequency carrier transmitted from this station is turned on by the action of the squelch relay in the associated receiver when a radio-frequency signal is received from either one of the terminal stations.

3. Extension of the headset, microphone, and carrier-control circuits of the terminal stations to the remote operating positions is provided in addition to the local handset and control facilities, so that each terminal station may be operated from either the local or remote position.

4. Operator at terminal A turns on the radio-frequency carrier F_2 of the associated radio set by means of a carrier-control switch associated with his handset. The radio-frequency signal F_2 arriving at the relay station generates a voltage in the squelch and carrier-operated relay circuits of the receiver, thus causing the carrier-operated relay to function and turn on radio-frequency carrier F_1 of the associated radio transmitter. Transmission of radio-frequency carrier F_1 from the relay station to the radio set at Terminal B completes the radio circuit between the two terminals and the operator transmits voice signals from A to B. Upon conclusion of this transmission, the operator at Terminal A releases the carrier-control switch on his handset, thus relinquishing control of the relay station to the operator at terminal B, who transmits voice signals from B to A in a like manner.

The multichannel very-high-frequency radio system is designed to operate in conjunction with tactical carrier telephone and telegraph terminal equipment to replace or supplement the telephone cable used as the transmitting medium. (See Fig. 3.) This terminal equipment

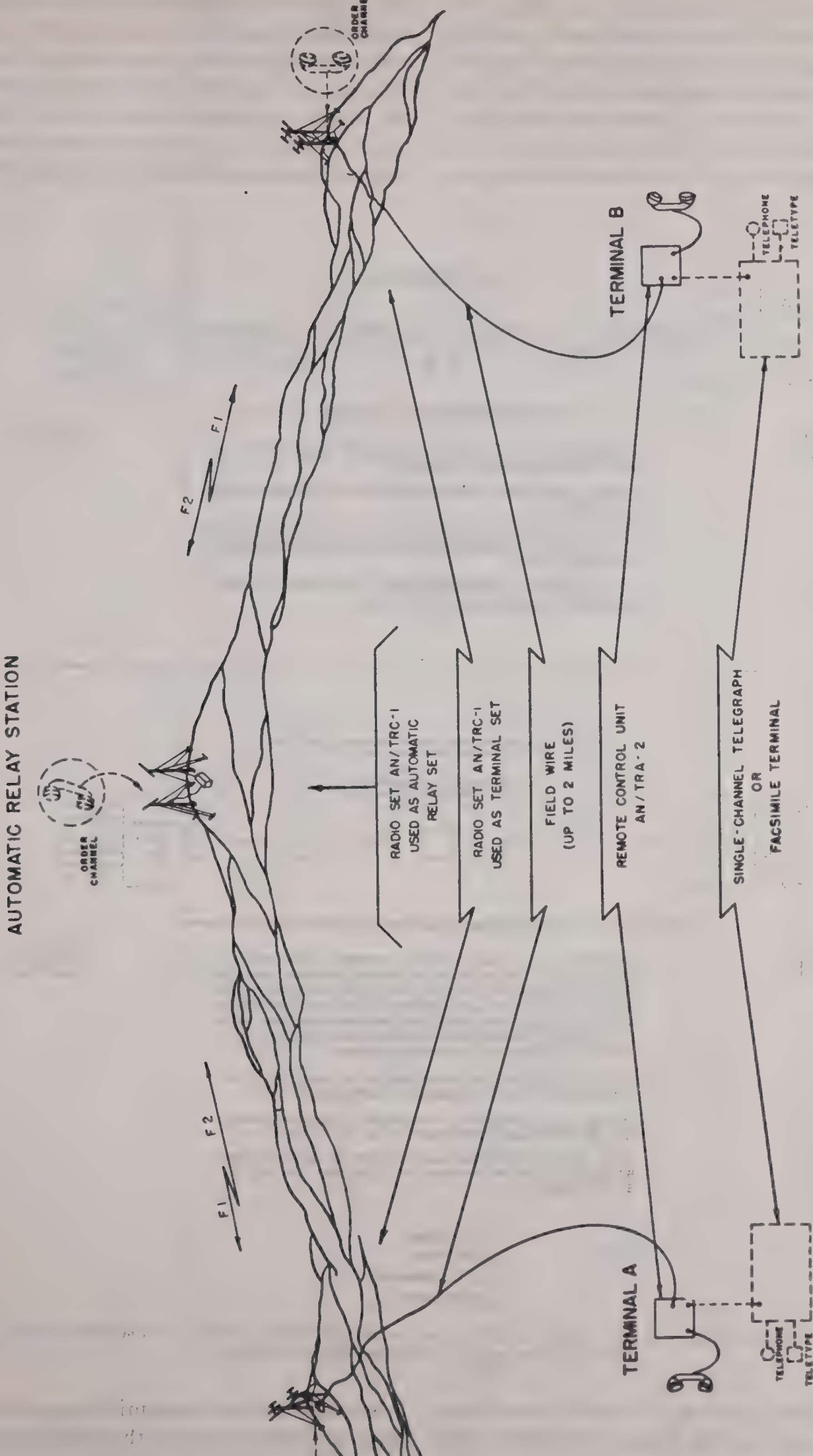

Fig. 2—Perspective view of two very-high-frequency radio-communication links. Simplex two-way system.

is common to the two systems and provides four telephone circuits, one of which is ordinarily used for voice-frequency telegraph operation to obtain four full or half duplex telegraph or teletype circuits. The telephone cable used is a four-wire, rubber-insulated spiral-four cable with loading coils at the junction points of the cable sections, and is made up in quarter-mile lengths. One pair of conductors serves to transmit in one direction and the other pair in the opposite direction. The cable may be strung aerially, laid on the ground, or buried in the ground by means of a cable plow. In long systems, most of the cable is ordinarily buried to minimize line trouble and the variations in loss or attenuation due to temperature changes. Intermediate cable repeaters are installed at approximately 25-mile intervals, depending upon the amount of prevailing noise and atmospheric static, and are adjusted manually at periodic intervals to compensate for variations in the cable attenuation caused by changes in temperature. With this order of repeater spacing and with good maintenance, system lengths up to three- or four-hundred miles may be employed when the cable is all buried. The radio system provides a transmitting medium which may be used to bridge gaps in the cable sections, replace the cable between the repeaters, or replace both the cable and the repeaters between the two terminals. Unlike the cable systems, the spacing between the radio-relay sets or radio-terminal sets depends primarily on the nature of the terrain along the radio-transmission path and the availability of installation sites for the radio equipment

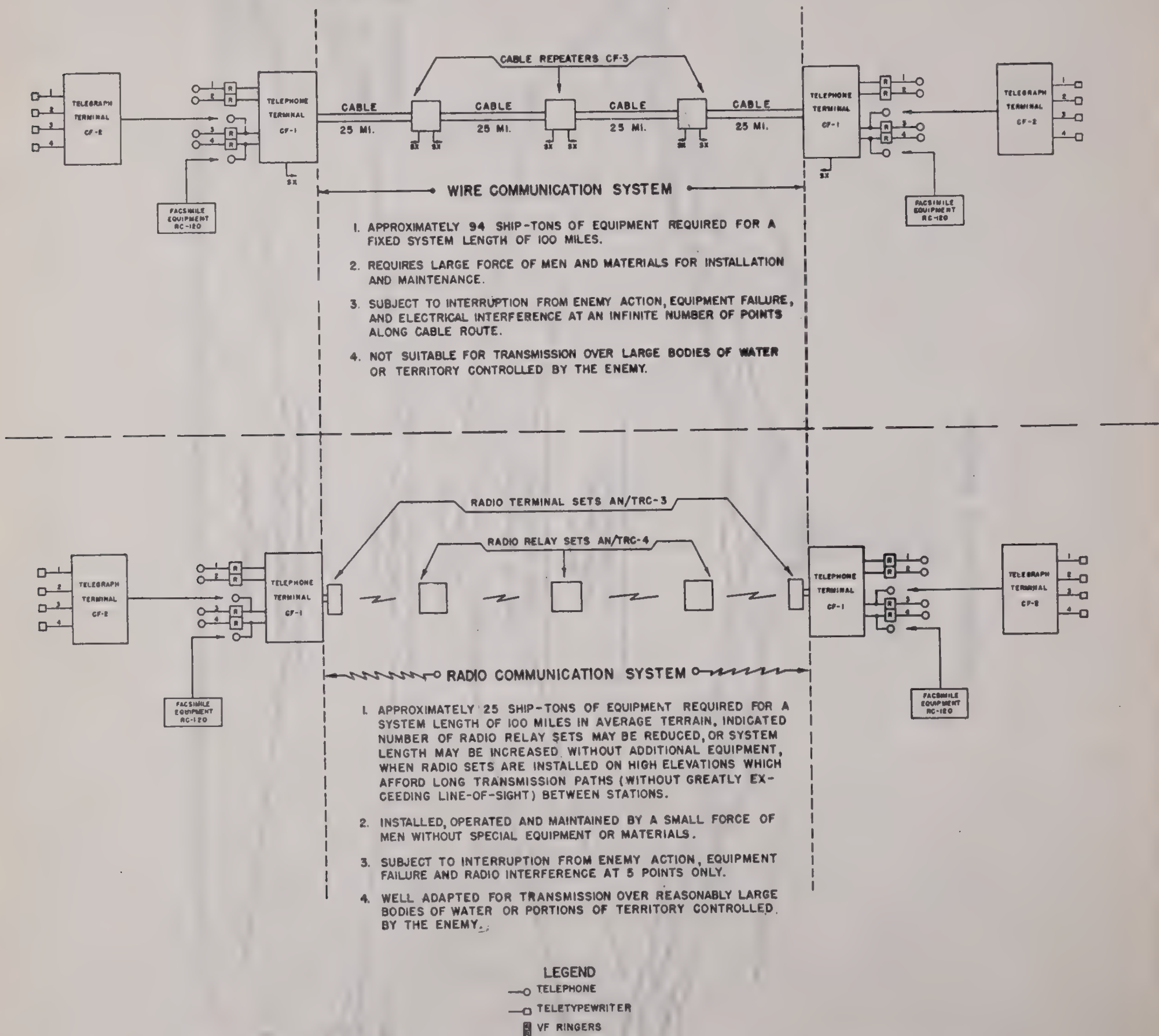

Fig. 3—United States Army tactical multichannel communication systems. Comparison of wire and very-high-frequency radio-transmission facilities.

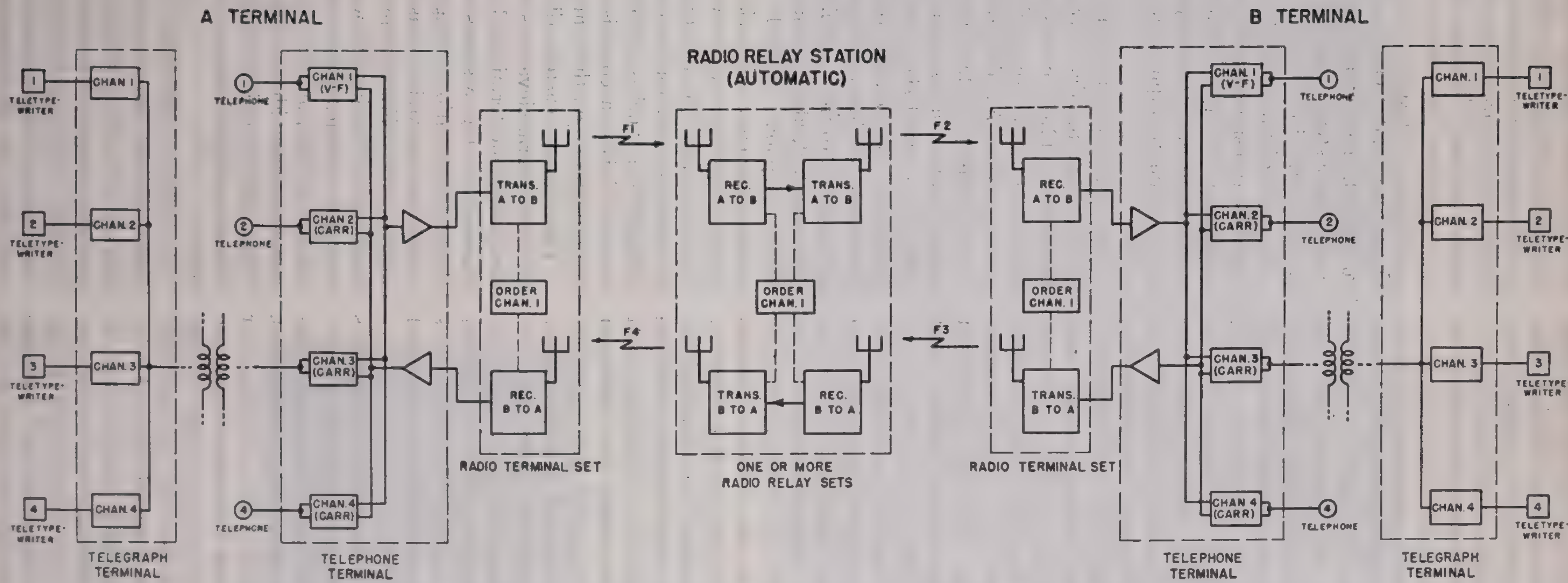

Fig. 4—Simplified functional diagram of United States Army multichannel very-high-frequency radio-relay communication system.

Very-high-frequency radio systems exceeding 100 miles in length may be satisfactorily employed without the use of intermediate relay sets when the terminal sets are installed on natural elevations of suitable height.

Fig. 4 shows a simplified functional diagram of the terminal-station equipment together with the very-high-frequency radio-relay station equipment. The basic component of the system is the telephone terminal which utilizes an audio-frequency band of approximately 200 to 12,000 cycles, divided into four separate telephone channels by means of the single-sideband suppressed-carrier technique. Channel 1 covers the voice-frequency band and is monitored by all stations in the system, thus serving as an "order channel" for supervisory control of the system. Channels 2, 3, and 4 are shifted by modulation into the carrier-frequency range and are used in a normal manner for telephone communication, or for voice-frequency telegraph or teletype communication by means of an associated telegraph terminal. Each of the four telephone channels passes frequencies between 200 and 2800 cycles to the modulator. The three lower sidebands from channels 2, 3, and 4, together with the voice frequencies from channel 1 are passed together to the common transmitting amplifier, and thence through a center-tapped repeating coil to the transmitting pair of the cable, or the input to the radio transmitter. In the cable system the center-tapped coil is used to provide an additional simplex circuit for signaling throughout the system. The receiving side of the telephone terminal, associated with the incoming pair of the cable, or output of the radio receiver, includes a simplex repeating coil, a receiving amplifier common to all four channels, and an equalizer for controlling the receiving gain. The four telephone circuits which the system provides are accessible for connection to a switchboard or individual telephones. Not shown in this diagram, but ordinarily associated with each telephone channel, is an auxiliary set of voice-frequency ringing equipment. In this equipment a 1000-cycle current, interrupted about 20 times per second, is generated and transmitted over the carrier circuit. At the receiving end of the system the low-frequency ringing current is sent toward the switchboard or telephone by means of another set of ringing equipment.

The voice-frequency telegraph terminal ordinarily is connected to the two-wire terminals of one carrier telephone channel. If necessary, additional telegraph terminals may be connected to the other telephone channels. The four telegraph or teletype channels are arranged for simultaneous two-way operation. Transmission between these terminals utilizes voice-frequency carrier currents of eight different frequencies between 595 and 1955 cycles. The local side of each telegraph channel is arranged to operate to outlying teletypewriter stations, telegraph repeaters, or switchboards over direct-current extensions or loop circuits. At the sending end, the signals received from the four direct-current telegraph circuits connected to the telegraph terminals are converted to voice frequencies; and at the receiving end the latter are reconverted to direct-current telegraph signals in the respective four connected circuits. Different carrier frequencies are employed in each direction of transmission for each telegraph channel. The terminals for the two ends of the telegraph channel are alike and are convertible by means of a switch to serve as either west or east terminals. The carrier telephone terminals require no change to make them suitable for use at either end of the system, since the transmission bands are the same in both directions.

Any one of the telephone channels may be used for facsimile transmission by means of suitable auxiliary equipment. Facsimile equipment RC-120 is ordinarily used for this purpose, and provides for the transmission of maps, photographs, and miscellaneous written material.

The combined output of the transmitting amplifier of the telephone terminal, occupying a frequency band of about 200 to 12,000 cycles, is connected to the input of the radio transmitter and thus modulates radio-frequency carrier F_1. This radio-frequency carrier is received at the relay station, demodulated, and connected to the input of an associated transmitter which retransmits the received signal on radio-frequency carrier F_2 to the next relay or radio-terminal station in the system. The output of the radio receiver at the terminal station is connected to the receiving telephone terminal where it is amplified, filtered, and demodulated into the individual telephone channels. The four radio-frequency carrier frequency channels at the relay stations are selected for simultaneous two-way operation. Channel 1 (voice-frequency) is monitored at each radio station and provision is made for the operators at these stations to utilize this channel as an "order channel" for supervisory control. This is accomplished without interference to communication on the other carrier channels.

The radio sets customarily are located at selected sites on high natural elevations and connected to the associated telephone terminals by means of spiral-four telephone cable. Fig. 5 shows the principal components of the terminal station arranged for operation in the field.

In order to provide a basis upon which to issue equipment for the different methods of employment, three basic sets of equipment were established which differ from one another only in the total number of components provided, and the use of certain auxiliary components to provide for different methods of operation. These sets of equipment and their principal operating components are designated and briefly described as follows:

1. *Radio Set* AN/TRC-1 (Fig. 6): Consists of one radio receiver and one radio transmitter, separately housed and shock mounted in weatherproof wooden carrying cases of identical size and shape, each being provided with a portable directional-antenna system. Also included are a portable gas-engine-driven power unit and a set of maintenance equipment. Each radio

set is normally issued to provide single-channel voice communication on a simplex basis in intermittent service, and includes provision for operation as an automatic radio-relay set when installed at an intermediate point in a radio-relay communication system. All components are readily transportable in a standard military two-and-one-half-ton truck and may be installed as a complete radio station by a crew of four men, in approximately one hour after arrival at the operating site.

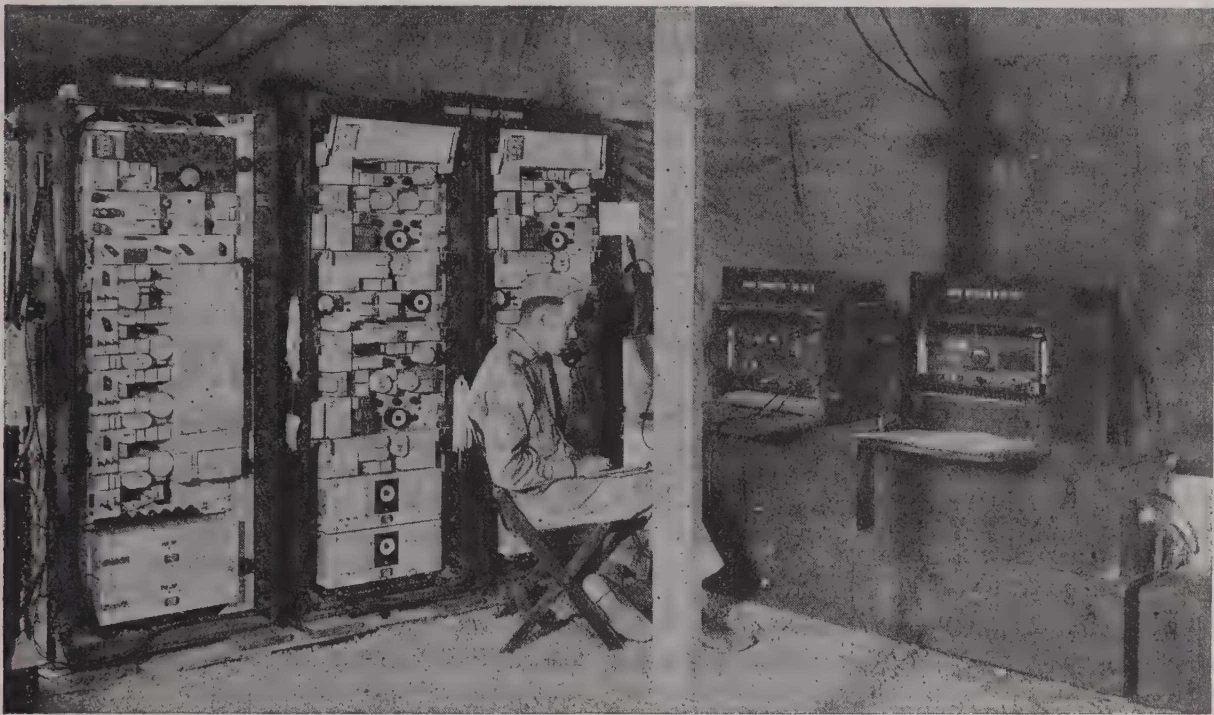

Fig. 5—Radio-relay-system terminal station.

3. *Radio-Relay Set* AN/TRC-4*:* Consists of two radio receivers, two radio transmitters, four antenna systems, and associated power and maintenance equipment. The basic components are identical to those used with radio set AN/TRC-1, from which set it differs only in the total number of such components provided, and the method of interconnection and operation. The complete radio-relay set is primarily intended for use as an automatic duplex radio-relay station interposed between two radio-terminal sets AN/TRC-3 or other radio-relay sets AN-TRC-4, at appropriate intervals to extend the length of the radio circuit between the two radio-terminal

are readily transportable in a standard military three-quarter-ton truck, and may be installed as a complete radio station by a crew of four men, in approximately one hour after arrival at the operating site.

2. *Radio Terminal Set* AN/TRC-3*:* Consists of one radio receiver, one radio transmitter, two antenna systems, and associated power and maintenance equipment. The basic components are identical and the method of operation is similar to radio set AN/TRC-1, except that radio terminal set AN/TRC-3 is intended for use under conditions of continuous operation at the terminals of a radio-relay communication system where uninterrupted service is a prime requisite. Although it may be used in the same manner as radio set AN/TRC-1, it is normally operated in conjunction with telephone terminal CF-1 and associated auxiliary equipment to provide a duplex radio circuit for the transmission of multichannel-telephone, voice-frequency telegraph (teletype), and facsimile-message traffic, thus providing a means for integrating the radio and wire systems into a single communication system. In order to assure continued operation with minimum interruption of service, an extra receiver, transmitter, and power unit are provided with each radio-terminal set for use as unit replacements in the event of failure of these components. All components

Fig. 6—Components of radio set AN/TRC-1.

stations. Since the radio-relay set forms an integral part of a radio circuit where uninterrupted service is a prime requisite, an extra receiver, transmitter, and power unit are provided with each set for use as unit replacements. All components are readily transportable in a standard military two-and-one-half-ton truck and may be installed as a complete radio station, by a crew of four men, in approximately two hours after arrival at the operating site.

4. *Radio Receiver* R-19/TRC-1: The radio receiver shown, together with its associated transmitter, in Fig. 7 operates on any single preset channel within the frequency band of 70 to 100 megacycles and is designed to receive frequency-modulated signals having a maximum deviation of plus or minus 30 kilocycles. It employs 17 vacuum tubes in a crystal-controlled double-conversion superheterodyne circuit.

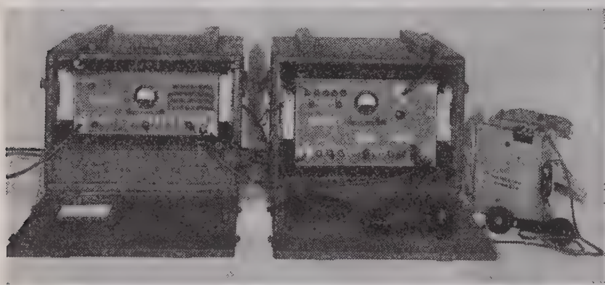

Fig. 7—Radio receiver and transmitter with associated field telephone.

Notable features of this receiver are the dual audio system and "carrier-operated" relay. The audio system includes a low-pass filter which may be inserted by throwing a panel switch to the position marked "single channel." This filter is used to restrict the received audio frequencies to a band of 200 to 3000 cycles when the radio set is used in a single-channel communication system. When the panel switch is thrown to the "multichannel" position, the filter is short-circuited out of the circuit and the audio system provides uniform output of the complete audio-frequency band 200 to 12,000 cycles required for multichannel transmission when the radio set is operated in conjunction with telephone terminal CF-1. The carrier-operated relay associated with the audio system is actuated by a squelch circuit, the sensitivity of which may be adjusted to trip the relay when the desired radio-frequency signal is received. The relay and associated squelch circuit are thus adjusted to control automatically the radio-frequency carrier of an associated transmitter when the receiver and transmitter are interconnected by means of a control circuit, and are used as an automatic radio-relay set. A meter and associated selector switch are also provided on the front panel for checking the operation of individual stages in the receiver.

The complete receiver includes a self-contained loudspeaker and power supply. The loudspeaker is used for monitoring purposes and the power supply is designed for operation from a 115 volt, 60 cycle, alternating-current power source. When prepared for operation it is connected to its associated antenna, power source, and radio transmitter by means of interconnecting cords. When prepared for transport in its carrying case it weighs 95 pounds.

5. *Radio Transmitter* T-14/TRC-1: The radio transmitter also shown in Fig. 7 is frequency modulated and operates on any single present crystal-controlled channel within the frequency band 70 to 100 megacycles. The nominal radio-frequency power output is 50 watts, and provision is made for reducing this power output to approximately 10 watts when the transmitter is used for communication over short distances. Frequency modulation is obtained by a phase-shift method wherein the modulator operates in conjunction with a crystal-controlled oscillator, the frequency of which is multiplied by a factor of 96 to produce a maximum deviation of 30 kilocycles. A frequency-correcting network, associated with the oscillator and modulator circuits, corrects the nonlinear audio-frequency output of the phase-shift modulator so as to provide a uniform response over the complete audio-frequency band 200 to 12,000 cycles. Maximum deviation is obtained at modulating frequencies of 200 to 3000 cycles, for single-channel operation, or 200 to 12,000 cycles, for multichannel operation, the desired mode of operation being established by appropriate selection of input circuit and adjustment of associated control switches. When the transmitter is operated in conjunction with telephone terminal CF-1 to provide multichannel transmission, the complete audio-frequency band 200 to 12,000 cycles is placed across the cable input terminals and is used to modulate the transmitter fully. Under this condition, four telephone conversations may be transmitted simultaneously, and the input to the modulator is adjusted so that each telephone conversation contributes 9 kilocycles deviation toward the maximum system deviation. Although this would appear to exceed the maximum deviation of 30 kilocycles, the peak voice levels rarely occur on all channels simultaneously, so that in practice the maximum deviation is never exceeded. A low-pass filter in the microphone input circuit restricts the modulating frequencies to a band of 200 to 3000 cycles when the transmitter is modulated with the local handset. By means of an associated control switch, the microphone input circuit may be arranged so as to modulate the transmitter to its full capability for single-channel operation, or at a level corresponding to channel 1 in the wide-band or multichannel system. This latter arrangement permits the local operator at the radio set to utilize the order channel (channel 1) for communication with associated radio stations in the circuit without interfering with transmission on the carrier channels in the system. Also associated with the audio-frequency input circuit to the modulator is a "cable compensator" or attenuator which may be adjusted from the front panel

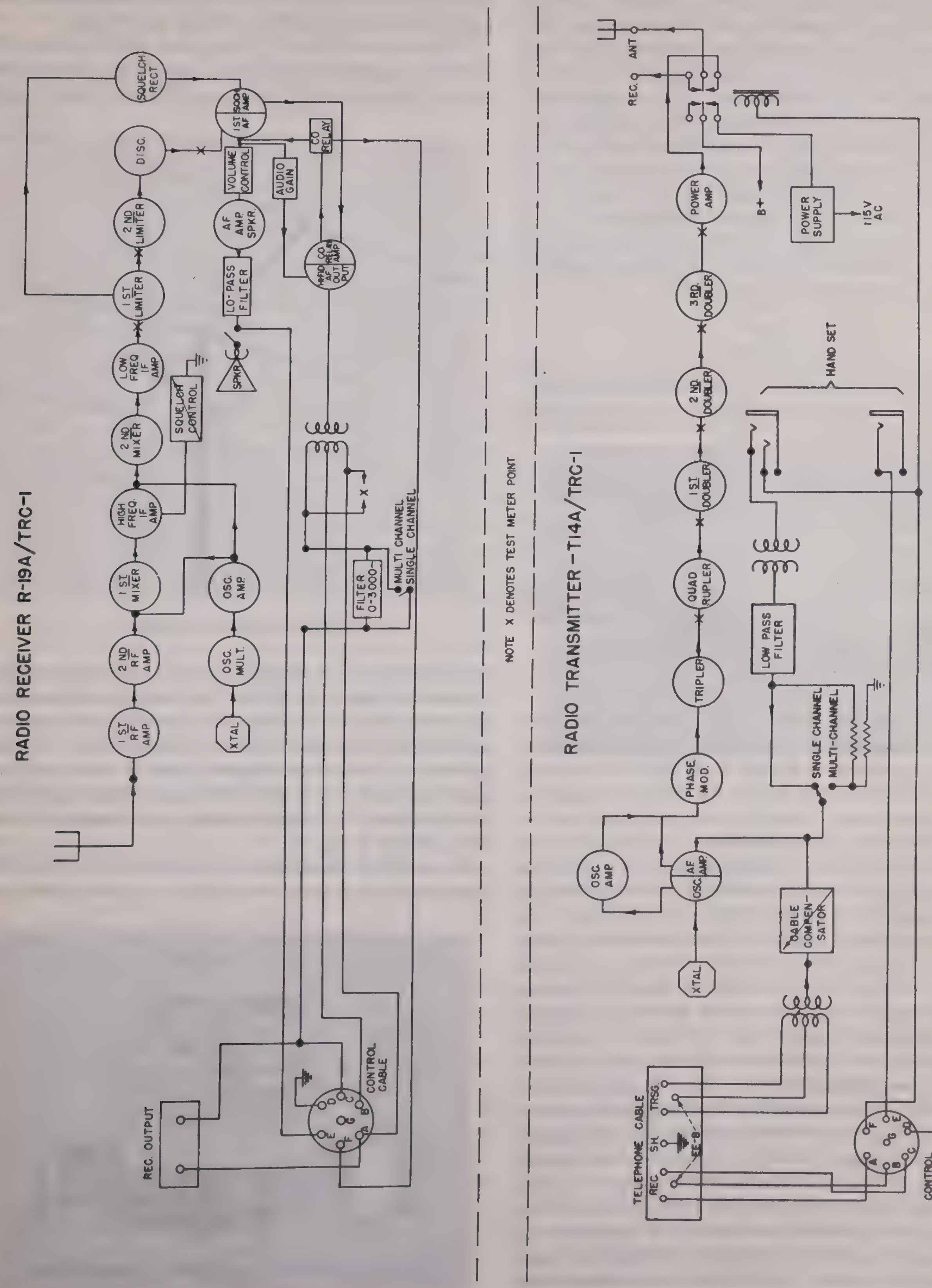

Fig. 8—Functional diagram of basic components of radio sets AN/TRC-1A, AN/TRC-3A, and AN/TRC-4A.

to increase the audio-frequency input level to the transmitter and thus compensate for loss suffered in transmission over the telephone cable normally used to interconnect the transmitter with its associated telephone terminal. A meter and selector switch are also provided on the front panel for checking the operation of individual stages in the transmitter. The complete transmitter includes a self-contained power supply, and weighs approximately 108 pounds when installed in its carrying case. When prepared for operation it is connected to its associated antenna, power source, and radio receiver by means of interconnecting cords. Fig. 8 shows a functional diagram of the radio receiver and transmitter and Table I shows the principal electrical characteristics of these two components.

TABLE I
Radio Set AN/TRC-1 Characteristics

Frequency-Modulation Transmitter	Frequency-Modulation Receiver
Power Supply: 115 V-60 cycles (built-in)	Power Supply: 115 V-60 cycles (built-in)
Power Output: 50 Watts Nominal 10 Watts Reduced	Type: Double conversion superheterodyne
Frequency Control: Crystal	Frequency Control: Crystal
Preset Frequencies: 1	Preset Frequencies: 1
Available Frequency Assignments: 300	Available Frequency Assignments: 300
Frequency Range: 70 to 100 megacycles	Frequency Range: 70 to 100 megacycles
Crystal Frequency: 730 to 1040 kilocycles (approximate)	Crystal Frequency: 7500 to 8740 kilocycles (approximate)
Multiplication Factor: 96	Special Features: Squelch-operated relay. Built-in loudspeaker.
Modulation: Phase shift	Sensitivity: 5 microvolts for 23 decibels signal plus noise to noise ratio, 50 per cent full deviation multichannel.
Deviation: ±30 kilocycles maximum	Radio-Frequency Band Width: 108 kilocycles for 30 decibels signal plus noise to noise ratio, 25 microvolts input, 50 per cent full deviation multichannel.
Audio Band Width: 200 to 3000 cycles single channel 200 to 12,000 cycles multichannel	Audio Band Width: 200 to 3000 cycles single channel 200 to 12,000 cycles multichannel
Weight in Carrying Case: 108 pounds	Weight in Carrying Case: 95 pounds.

6. *Antenna System* AS-19/TRC-1 (Fig. 9)*:* The antenna system consists of a 3-element horizontally polarized array supported on a steel mast which is mounted on a mast base in such a manner that the complete antenna system may be rotated to orient the array in the desired direction of transmission. The mast is made up of 5-foot tubular-steel sections which are easily assembled together to provide different antenna heights up to a maximum height of 40 feet above ground, and the complete system is held in place by means of rope guys. The antenna array consists of a directly excited horizontal dipole, with parasitically excited director dipole and reflector dipole, both of which are spaced a quarter wave length from the driven dipole, by means of adjustable support members. All elements are calibrated and are adjustable to any operating frequency in the band 70 to 100 megacycles. The dipole elements are all interchangeable and the parasitic-element support members are demountable from a common mast head in such a manner that the antenna may be used as a one-, two-, or three-element system, the latter system having a forward power gain of approximately 6 decibels above a dipole antenna at the same height. Although the beam width of this antenna is quite wide and affords little privacy, it is considered to be the minimum practicable, consistent with the requirements of portability and flexibility of employment. The antenna is connected to its associated radio receiver or transmitter by means of a flexible solid-dielectric radio-frequency transmission line having a characteristic impedance of 50 ohms.

7. *Power Unit* PE-75*:* The power unit consists of a 2500-watt gasoline-engine-drive alternating-current generating set designed to generate a 120-volt single-phase

Fig. 9—Close-up of antenna array.

60-cycle current. A single-cylinder gasoline engine of the manual-starting type drives the single-phase generator by means of two V belts. The speed of the engine is automatically controlled by a built-in fully enclosed governor. The complete power unit is mounted on a steel skid base and weighs 325 pounds when assembled for operation. This unit is shown with associated radio components in Fig. 6.

8. *Amplifier Equipment* AN/TRA-1 (Fig. 10)*:* This equipment is furnished as auxiliary equipment for use in

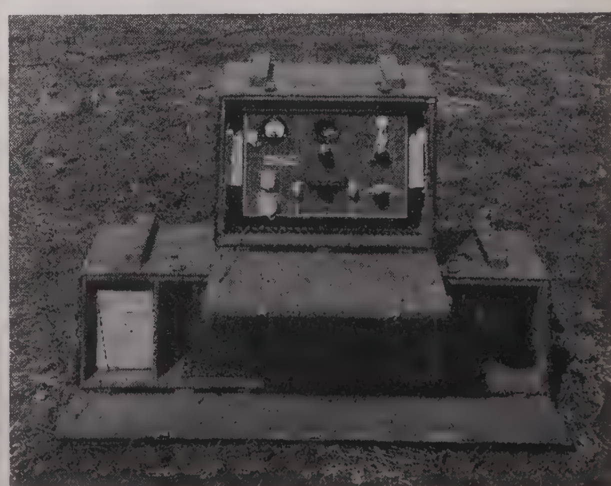

Fig. 10—Amplifier equipment AN/TRA-1.

conjunction with the radio transmitter to increase the radio-frequency power output when increased power is required to improve signal strength on unusually long or noisy circuits. It consists of a push-pull class C radio-frequency amplifier, designed to provide a maximum power output of 250 watts, and is furnished with a separate power supply. The amplifier weighs 90 pounds and the power supply weighs 195 pounds when installed in their respective carrying cases.

III. Employment in Tunisian, Silician, and Italian Campaigns

In December, 1942, Allied Force Headquarters, North Africa, placed before the War Department the first de facto field requirement for a radio-relay communication system. This system was to extend from Allied Force Headquarters to subordinate headquarters in the forward combat areas providing facilities whereby commanders in these forward areas could maintain reliable and rapid communication with the rear. Drawing upon its experiences in the Carolina maneuvers of 1941, Coles Signal Laboratory was able to establish the major technical characteristics of the proposed North African System and, with the close co-operation of manufacturers, make available commercial very-high-frequency frequency-modulation police-type radio equipment.

After a number of weeks of preparation in the North African Theater of Operations, during which techniques for the application of two-tone teletype to the radio equipment were developed and tests conducted to verify the suitability of the equipment for the task at hand, a simplex single-channel radio-teletype system was placed in operation on April 20, 1943, extending from a semi-fixed 250-watt terminal station in Algiers, through three successive 250-watt radio-relay stations into Tunisia. (See Fig. 11.) A mobile 50-watt terminal station was attached to the American Combat Headquarters consisting of the Second Corps, reinforced, to complete the circuit from Algiers and provide the only direct communication with this headquarters throughout the ensuing phase of the Tunisian Campaign. This circuit carried the bulk of all operational and administrative traffic to and from Second Corps. The terminal moved with the Corps Headquarters from Beja to Sidi Nsir and thence to Mateur, providing communication immediately upon establishment of each position. A fourth relay station was held in readiness during this advance until the famous assault upon Hill 609 permitted its installation upon an adjacent promontory, whereupon it was placed in operation to provide an additional relay section to the mobile terminal as the latter proceeded beyond range of the third relay station. The resulting over-all system length was 379 miles. This operation represented the first employment of radio-relay systems and of radio teletype in tactical operations by Allied Military Forces.

As the campaign progressed, two additional mobile terminal stations were placed in service, moving with their respective headquarters to Bizerte and vicinities about Tunis. The three terminal stations operated alternately with the Algiers terminal and with each other through the relay station near Hill 609. The traffic load reached a maximum of 16,000 word groups per day, 12,000 groups being handled with Algiers, and 4,000 groups between the forward terminals. Pending the establishment of wire lines, a task greatly magnified by the rapidity of movement of the terminal headquarters and by the incidence of enemy action, these radio circuits provided vital communication facilities at critical moments during, and immediately after, the campaign remaining in operation until the middle of August, 1943. The total system length during this period reached a maximum of 418 miles over rugged terrain, representative samples of which are indicated.

Fig. 12 shows the transmitter site of one of the relay stations. The radio receivers were located a few hundred yards to the right. A mobile power unit also was located approximately 100 feet from this site serving both receiving and transmitting equipment.

Fig. 12—Transmitter site of radio-relay station in North Africa.

In the installation of this system, some map studies and preliminary reconnaissance of locations were made to predetermine the relay-station sites.

From the opening of the Sicilian Campaign on July 7, 1943, until August 9, 1943 a duplex radio circuit shown in Fig. 13 was operated between Sidi-bou-Said, near Tunis, and Malta, with relay stations on Cape Bon and Pantelleria, a total distance of 243 miles, all over water. Facilities were made available for the manual relay of traffic from this system to the simplex Algiers-Tunis radio system and also to a wire-teletype circuit over a parallel route which, by this time, had been placed in operation. Although operating teams had been dispatched to Malta and Pantelleria considerably prior to the date of the invasion of Sicily, the necessity for observing radio silence precluded preliminary testing of the circuit other than continuous listening at these points. Consequently, there was no certainty that the circuit would be operable. However, when operations began, signal levels were consistently above marginal limits despite the relatively great distance, 148 miles,

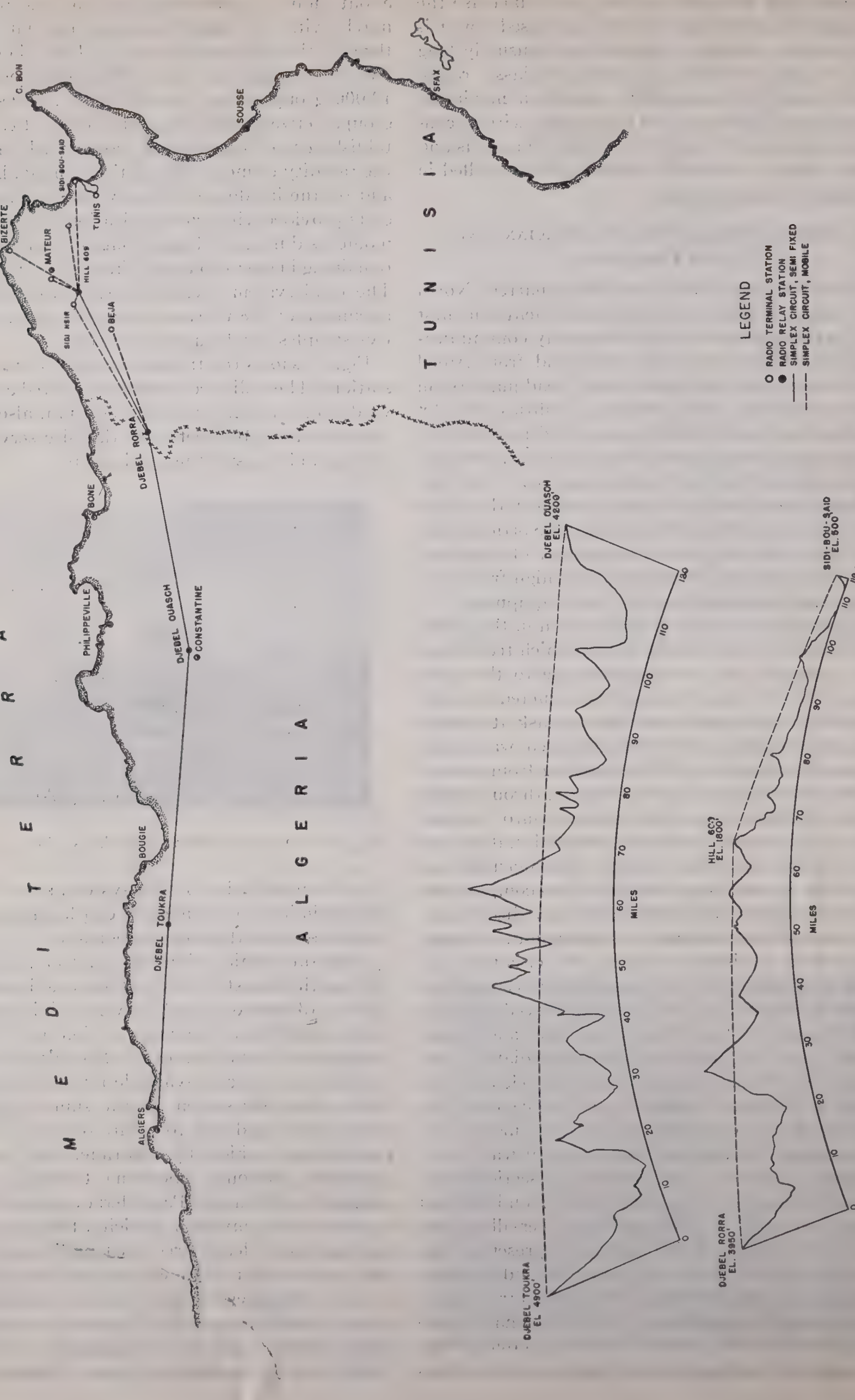

Fig. 11—Single-channel very-high-frequency radio-relay circuits used during Tunisian campaign (April to August, 1943).

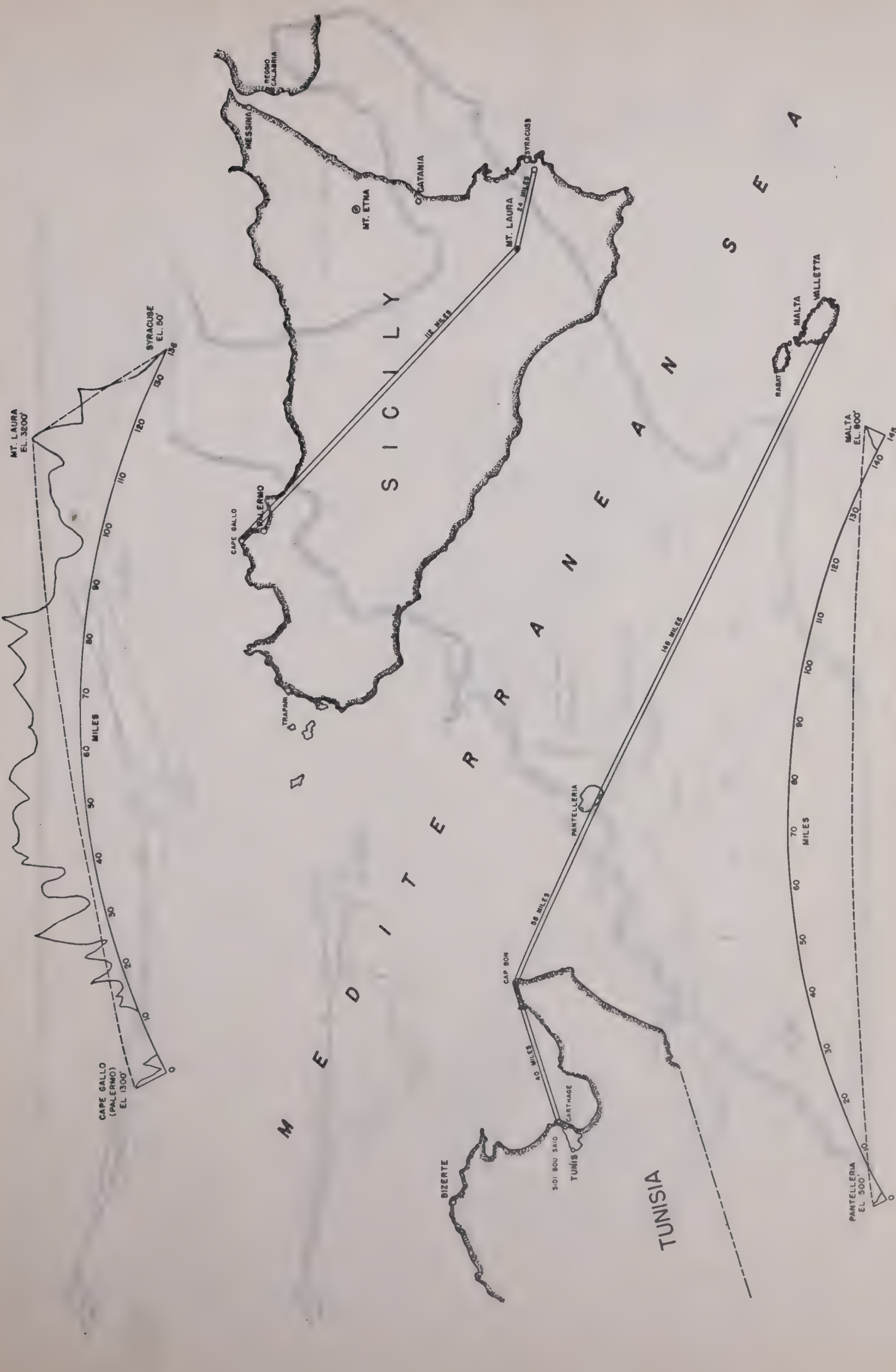

Fig. 13—Single-channel very-high-frequency radio-relay circuits used during Sicilian campaign (July to September, 1943).

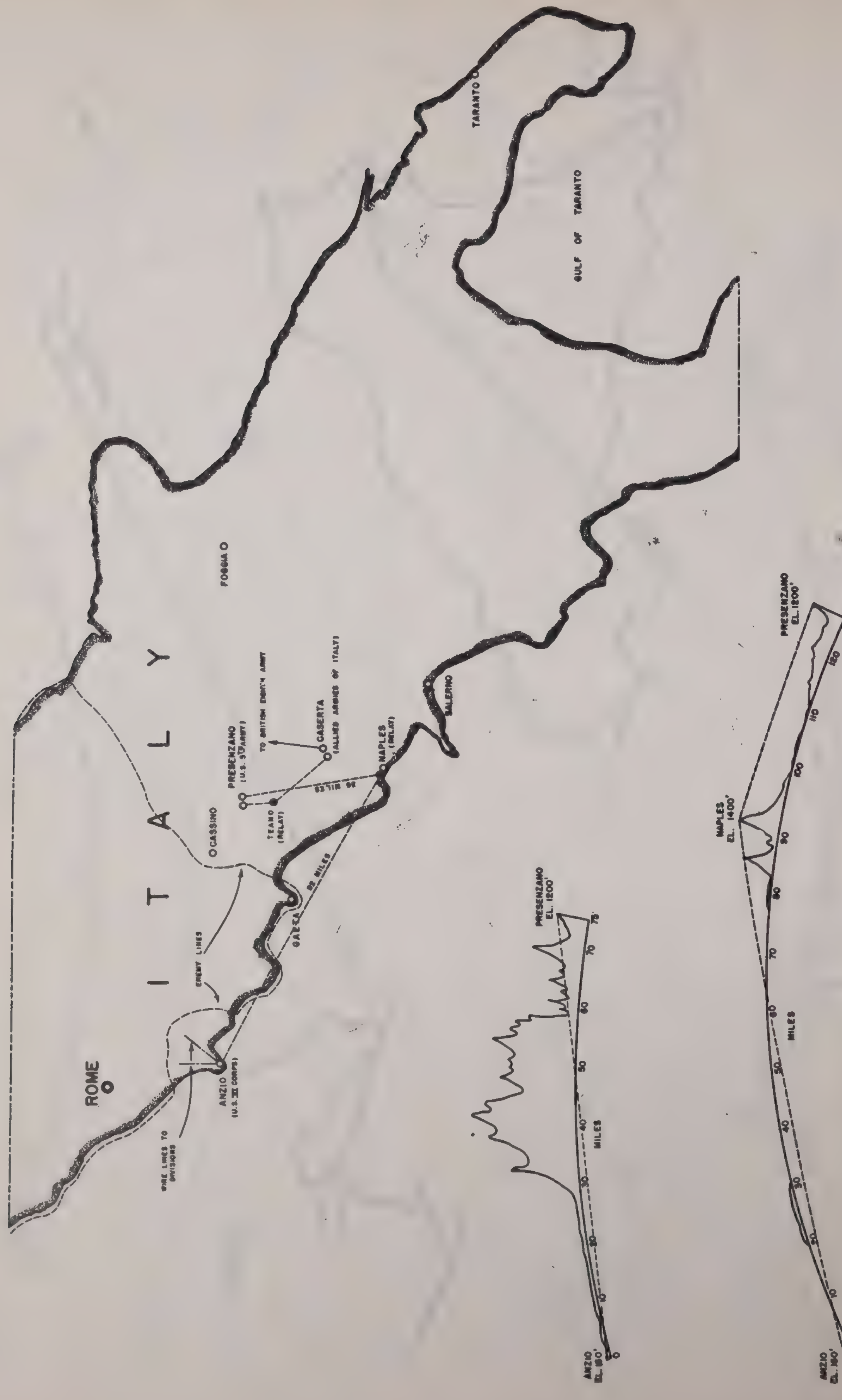

Fig. 14—Single-channel very-high-frequency radio-relay circuits used in Anzio sector during Italian campaign (February, 1944).

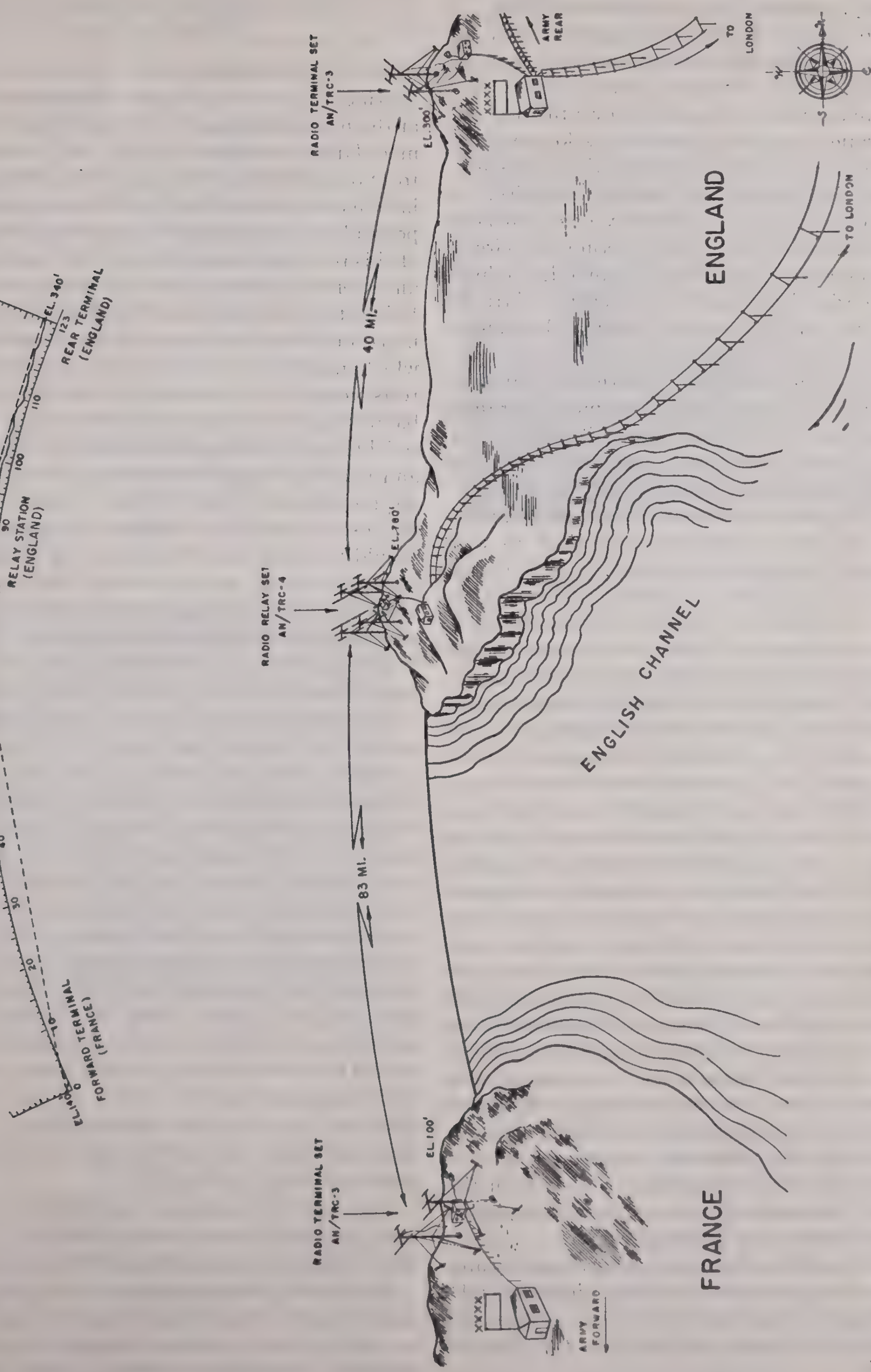

Fig. 15—Perspective view of first United States Army multichannel very-high-frequency radio-relay communication system across English Channel (June, 1944)

between Pantelleria and Malta and the below line-of-sight locations of these stations as indicated in the profile.

Subsequently, a duplex system, also shown in Fig. 13, was operated on Sicily for a period of approximately one month, linking Headquarters of the American Seventh Army at Palermo with Fifteenth Army Group, near Syracuse, commanding the American Seventh and British Eighth Armies. One relay station was located atop Mt. Laura. There was little or no choice of sites possible, the locations being dictated by tactical necessity. Although the profile indicates a relatively poor transmission path between Mt. Laura and Palermo, the circuit operated satisfactorily and provided valuable facilities because of the prior destruction by the enemy of trunk-line wire circuits over appreciable distance throughout the island.

During the Italian Campaign, a variety of missions was executed with this radio-relay equipment operating in simplex circuits, generally between Fifteenth Army Group Headquarters and the subordinate American Fifth and British Eighth Armies. These circuits provided highly important communication facilities between the headquarters concerned, inasmuch as wire lines were subject to frequent outages by enemy action. One illustration of the very important need of radio-relay facilities is illustrated in Fig. 14, wherein communication was maintained from the American Sixth Corps at Anzio beachhead to Fifth Army at Presenzano, thence to the Commanding Fifteenth Army Group, which also was linked with the British Eighth Army on the Adriatic side of the peninsula. As the profile indicates, the location of the relay station near Naples routed the radio circuit over favorable terrain between Anzio and Presenzano to avoid the unfavorable terrain in the direct path between these two points. The facility thus provided bridged enemy-held territory in a manner impossible of accomplishment with wire lines, and furnished the primary means of communication with Anzio for this vital operation. During this phase, the radio-teletype service was extended through the Sixth Corps teletype switchboard and over wire lines to the combat divisions. This operation illustrates the flexibility and important use of radio-relay equipment as a primary means of communication when equivalent wire circuits cannot be made available. Of all the missions accomplished with the radio-relay equipment to this time, the Anzio circuit is considered to have been the most valuable. The peak traffic over this circuit reached a maximum of 20,000 word groups per day.

Subsequently, as the campaign progressed northward, these circuits were displaced and new circuits established, extending to the island of Corsica, the south coast of France, and thence northward in the drive toward Germany.

The preceding examples are indicative of the tasks which tactical communication equipment may be called upon to accomplish in comparison with the missions of carefully engineered and permanently located fixed equipment.

IV. Employment in Normandy Invasion and Battle of France

Early in 1944, plans for the invasion of the European continent across the English Channel included the use of the newly developed very-high-frequency frequency-modulation multichannel AN/TRC-1 equipment. Prior to D day, the Signal Corps in Great Britain forwarded information to the War Department concerning the topography of the proposed cross-channel route. A replica of this route was selected along the coast of Maine, and an extensive series of tests performed by Coles Signal Laboratory with models of the new equipment to determine and solve any technical problems of propagation which might be involved in the coming operation. These tests verified the propriety of the choice of frequency band for operation over moderately long distances with reliable signal strengths permitting teletype operation and maximum signal-to-noise ratio consistent with siting requirements which in many cases would preclude the use of true line-of-sight transmission paths. It should be noted that these tests, as well as subsequent operations over water, covered distances considered most optimistic by engineering experts. Accordingly, a wide application of the equipment was foreseen by the War Department in establishing extensive plans for integrated multichannel wire-and-radio circuits.

The dawn of D day, June 6, 1944, saw facilities installed in England and ready for the cross-channel operation, and equipment on its way to Normandy following closely behind the first wave of the invasion. Within two hours after arrival of the terminal station (at a site on the beachhead) in France, June 8, 1944, the cross-channel circuit (Fig. 15) began operation. The initial service provided was the transmission of vital air-reconnaissance information from a tactical air-command headquarters to the invasion forces. Aerial photographs of enemy positions which had been made by reconnaissance aircraft, flown back to England, developed, printed, and marked for military objectives, were transmitted by facsimile back to the invasion forces and used in directing appropriate offensive action. This was the first instance of facsimile transmission to United States forces in France. A reproduction of a typical facsimile message is shown in Fig. 16.

Very shortly thereafter, multichannel-telephone-and-teletype facilities were made available by the installation of standard army carrier terminal equipments.

Additional terminal equipment was bridged across the channel-coast relay station to permit operation of this station as a radio terminal in event of failure of the inland section or of the necessity to route traffic to other points in England served by existing British wire lines from the relay site. Illustrative of the flexibility of the communication circuits was the integration with British

wire-terminal equipment. Thus the cross-channel facilities could be extended to points throughout Great Britain in addition to the original air base, and did provide telephone talking circuits from General Eisenhower and his associates at Central Headquarters in England to the field commanders of First United States Army on the continent, as well as teletype service between the respective command echelons.

The site of the channel-coast relay station is shown in Fig. 17. Although the vertical rhombic antennas depicted therein were provided as insurance against weak signals across the channel, the three-element horizontal arrays proved to be entirely satisfactory with the normal mast height of 40 feet. In the opposite direction, toward the inland terminal, the three-element arrays also were used, but with reduced height to improve security. In this photograph, the antenna wires are retouched for clarity.

As the details of the initial use of radio-relay equipment became known, urgent requirements were presented by other combat organizations and services of the Armed Forces. The First United States Army, in accomplishing the initial invasion on the Normandy coast, achieved considerable distinction in this employment by controlling this circuit and having obtained and operated additional equipment to extend facilities on the continent from Army Headquarters to Corps, and Corps to Divisions, and between Corps within the Army. Following these outstanding uses, other armies were quick to follow suit as they became operational by equipping their units similarly. Air Force base establishments also availed themselves of the opportunities to provide early multichannel-radio circuits pending establishment of equivalent wire facilities.

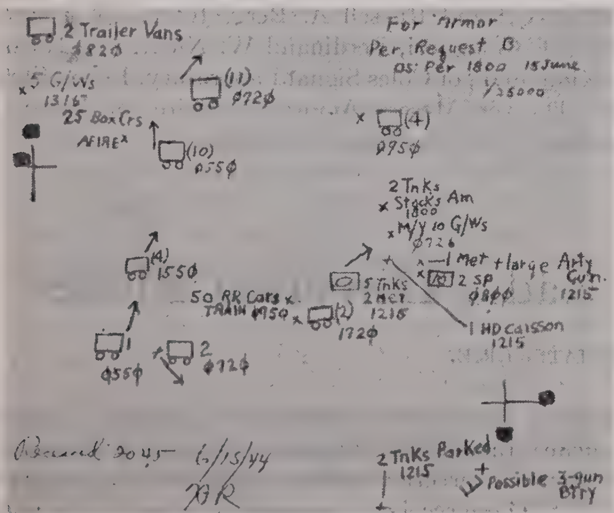

Fig. 16—Teledeltos recording of map overlay sent to American Expeditionary Forces.

A typical employment of the radio-relay equipment by the Third United States Army occurred during General Patton's dash across France. After the break through at St. Lô, this Army relied upon these radio circuits for communication back to its commanding Twelfth Army Group, and forward to its respective Corps, and in several instances to its Divisions. Initially, these circuits comprised single sections between the respective terminal headquarters. Then, as these elements moved forward, extending their lines of communication, radio-relay sets were interposed to extend the lengths of the systems. Later, as wire circuits followed through, relay stations became terminals by direct connection to the wire circuits and the rear radio installations then were either removed from service or continued in operation as emergency facilities in the event of failure or overload of the wire facilities.

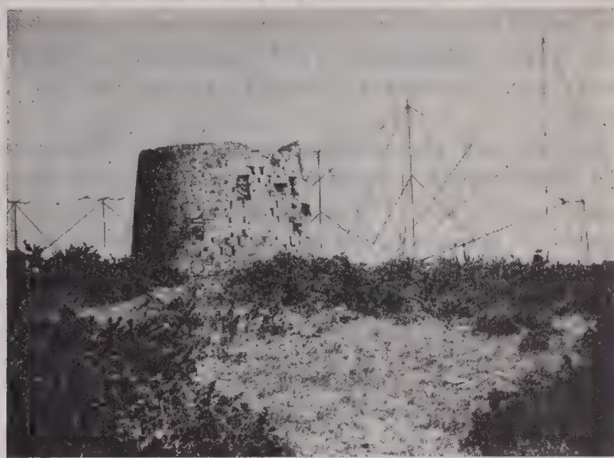

Fig. 17—Operating site of first radio-relay set AN/TRC-4 used in United States Army very-high-frequency radio-relay circuit across English Channel.

As the Armed Forces progressed across France to the Siegfried Line, additional radio-relay facilities were established for both tactical requirements in the forward areas and administrative purposes in the communications zone to the rear. Additional cross-channel radio-relay systems were installed from Paris to London, other types of radio circuits activated, existing wire lines throughout the occupied area rehabilitated, new wire lines installed, and the whole integrated into a comprehensive telephone, teletype, and telegraph network covering an area in Europe equivalent in size to that from New York to Chicago and from Detroit to Atlanta.

Many examples occurred during this campaign to demonstrate the outstanding value of multichannel radio-relay communication facilities to military operations both as a primary means to cross territory held by the enemy in situations similar to that at Anzio beachhead, or rendered impassable by enemy action or terrain characteristics, and as a supplementary facility to wire and other radio circuits. River crossings were established under enemy fire which imposed prohibitive losses in men and material during attempted installations of wire circuits. Emergency facilities were provided, when the main French underground-cable system failed as a result

of combat operations, whereby the Continental Headquarters was furnished direct telephone and teletype communication to England and thence to the United States by interconnection with transatlantic communication facilities. The importance of this emergency operation is illustrated by the quotation of Major-General W. Rumbough, Chief Signal Officer, European Theater of Operations, in a Commanding Generals' conference: "In spite of this very serious cable interruption, and I do not think any single trouble could have been worse, we handled 2709 messages . . . ; that is nearly two messages per minute throughout the 24 hours."

In reporting the employment of the multichannel very-high-frequency radio-relay communication equipment to the War Department, General Rumbough stated: "It is believed that this operation marks an important milestone in military radio communication. Tactical field-radio equipment has been successfully integrated with wire-line and terminal equipment to form a system comparable in reliability and traffic capacity to all-wire systems."

V. Conclusions

The favorable reception and praise given to very-high-frequency radio-relay systems is due principally to the inherent advantages from a military point of view of such systems. These are briefly summarized in Fig. 3. Since logistics are of prime importance in military operations, the large saving in shipping space and tonnage as well as installation and maintenance personnel by the use of very-high-frequency radio relay is a major contribution in relieving the strain on transportation facilities and the Signal officers' resources.

The successful employment of this system in the Army under difficult conditions indicates greatly increased commercial use of such systems where full advantage may be taken of the unlimited design possibilities opened up by new techniques for such services as point-to-point relaying and multiple use of single radio-frequency channels and facilities.

VI. Acknowledgment

The authors wish to express sincere thanks and appreciation to all their associates of the War Department, Signal Corps Ground Signal Agency, and Industry, through whose close co-operation and tireless efforts the development and production of the frequency-modulation radio-relay equipment was made possible and who contributed valuable information for the preparation of this paper. Particular credit is extended to Mr. Walter E. Bonham, of Coles Signal Laboratory, for his persevering efforts, and to the following civilian employees of the Signal Corps for oustanding duty in combat zones in placing equipment in operation and instructing troops in its use:

In the North African Theater, Messrs. John J. Kelleher, Office of the Chief Signal Officer, Washington, D. C.; and Russell A. Berg, Joseph H. Durrer, Victor J. Colaguori, Ferdinand W. Niedt, and Harold H. Kinnaman, of Coles Signal Laboratory. In the European Theater, Messrs. Amory H. Waite and Victor J. Colaguori of Coles Signal Laboratory.

A New Type of Automatic Radio Direction Finder*

C. C. PINE†, ASSOCIATE, I.R.E.

Summary—**A system of automatic radio direction finding is described that operates on the principle of effectively converting the radio-frequency currents developed in two low-impedance loops into direct currents of proportional amplitude and having the same relative polarity as the instantaneous values of the radio-frequency currents developed. By utilizing the two fixed loops in space quadrature, direct currents are obtained which can be applied to an indicating meter or cathode-ray tube in such a manner as to give a continuous visual indication of the angle, in the horizontal plane, at which an incident wave is striking the loop assembly.**

Introduction

The USE of radio-wave transmission and reception for direction-finding purposes is well known and has been developed into a highly specialized field.[1] However, in recent years this field has been so expanded that it has resolved itself into many special branches. Included in this category is the development of automatic direction-finding equipment for use aboard aircraft. These receivers are generally designed to operate on frequencies from 200 to 1800 kilocycles, and make use of the normally polarized ground wave radiated from transmitters operating in this band. This paper is devoted to describing an automatic direction-finding system developed primarily for such use.

There are many requirements that must be met if a system of automatic direction finding is to be accepted by the aircraft industry. Among these requirements are reliability, simplicity, and light weight. All of these factors have been considered in the system here described.

Theory

Let us consider for a moment a crossed-loop assembly connected to a radio goniometer, as in Fig. 1. As an incident wave strikes the loop assembly at angle θ (Fig.

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[1] C. T. Solt, "The development and application of marine radio direction finding by the United States Coast Guard," Proc. I.R.E., vol. 20, pp. 228–260; February, 1932.

2a), with reference to loop A, currents will be induced in each loop as may be calculated by the following trigonometric equation.[2]

$$I_{la} = I_{la}^{\max} \cos \theta \quad (1)$$

$$I_{lb} = I_{lb}^{\max} \sin \theta \quad (2)$$

where la indicates loop A

lb indicates loop B

θ is the angle loop A makes with the incident wave in the horizontal plane.

Obviously, the currents in the crossed windings of the goniometer (Fig. 1) will have a direct relationship to those of the loops, and the resultant magnetic field will have the same space relationship with reference to winding A as the incident wave has to loop A. This may be shown as follows:

$$\tan \phi = I_b/I_a = (I_{lb}^{\max} \sin \theta)/(I_{la}^{\max} \cos \theta) = \tan \theta \quad (3)$$

where $I_{la}^{\max} = I_{lb}^{\max}$ due to identical electrical characteristics of loop A and loop B

I_a = current in winding A

I_b = current in winding B

ϕ = angle of resultant magnetic field set up in windings of goniometer.

If a search coil is introduced into the center of this resultant field, the coil can be rotated so as to pick up the maximum or minimum values of the field. By connecting the search coil to a properly constructed receiver, an aural indication of the maximums and minimums can be heard in the receiver output. To measure the angle ϕ, a pointer is attached to the search coil, and the position of the coil is noted on a 360-degree scale as it is rotated to one of the null positions. Of course, this system of aural direction finding is bidirectional, due to the fact that two maxima and two nulls will be heard as the search coil is rotated through 360 degrees.

For a purely imaginative illustration, let us assume that the currents applied to the windings A and B of the goniometer are direct currents, the values of which follow the same expressions as were derived for the radio-frequency currents. Now, by replacing the search coil with a magnetic armature such as a very small compass needle, it readily can be seen that the armature will align itself with the major axis of the magnetic field and therefore indicate the angle ϕ. Further, as the winding currents are slowly changed relative to each other, in the same manner as the loop currents would be changed as a wave source is moved around the loop assembly, the armature will continue to indicate the angle because it has the ability to recognize the polarity as well as the angle of the flux field. Thus, we would have an indicating device which would give a continuous reading of the angle at which a wave is striking the crossed-loop assembly.

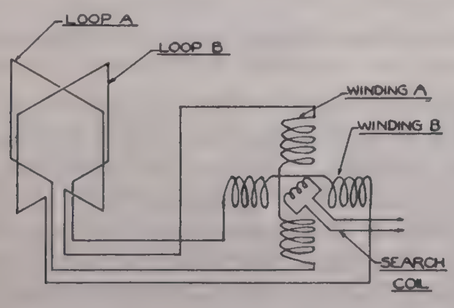

Fig. 1—Simplified circuit of crossed loops connected to a goniometer.

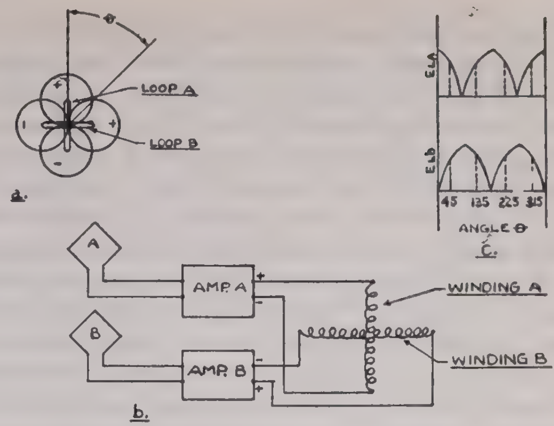

Fig. 2—Quadridirectional indication with a crossed-winding indicator.

Many problems present themselves when attempting to put the above theory into practical use. Not only must the method of development be met, but in order to make this system practical for aircraft usage, the requirements set forth previously in the introduction must be given every consideration.

Indicator Development

Simplicity demands that the loop assembly be composed of two small aperiodic loops, and that these loops be placed in a fixed position, that is, nonrotatable. Fig. 2a shows the pattern of the voltages developed in the crossed loops as a source of propagation is moved around them through 360 degrees. Now, if each of these loops is connected to a separate radio-frequency amplifier, as in Fig. 2b, the radio-frequency voltage output of each can be written

$$E_{la}' = \mu(E_{la}^{\max} \cos \theta) \quad (4)$$

and

$$E_{lb}' = \mu(E_{lb}^{\max} \sin \theta) \quad (5)$$

where μ is the total amplification factor of each radio-frequency unit. It is to be understood that the characteristics of each amplifier are identical.

When these voltages are rectified, the resulting direct-current output voltages, E_{LA} and E_{LB}, for different values of θ may be represented as shown in Fig. 2c. When these direct-current voltages are applied to the respective windings of a crossed-winding indicator, in the center of which is placed a small polarized magnetic armature, the armature will be acted upon in such a manner as to give a quadridirectional indication of the angle θ. This may be illustrated as follows. Let the angle θ of the incident wave be some such value as 45

[2] R. Keen, "Wireless Direction Finding," Iliffe and Sons, London, England, 1938, chapter 15.

degrees with reference to the plane of loop A. From Fig. 2c we may obtain values which, when substituted in (3), will show that the angle ϕ is equal to 45 degrees. Now, should the source of the radio wave be moved around the loop assembly so that it is being received from an angle of 135 degrees, it will be evident that the currents flowing in the windings A and B will be of the same amplitude and polarity as those flowing at 45 degrees. (See Fig. 2c.) Therefore, the angle ϕ will again be 45 degrees. This will also hold true for reception from 225 and 315 degrees. Thus by calculation it may be shown that the armature of the indicator will traverse the angles from 0 to 90 degrees and back twice, as a complete rotation of the radio-wave source is made around the loop assembly.

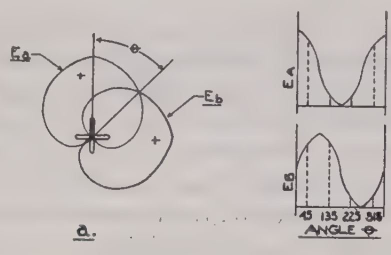

Fig. 3—a. Cardioid pattern obtained when a sense antenna voltage is combined with the loop voltages.
b. Rectified output of amplifiers with cardioid-pattern input.

The above condition of quadridirectional indication can be traced to the fact that the radio-frequency expressions, as set forth previously, are not valid for all angles of θ when applied to the above specific case, but are interrupted abruptly as the sine and cosine values become negative. This is, of course, due to the characteristics of rectification.

As can be seen readily from the foregoing, the indications obtained are of no value as far as automatic direction finding is concerned. The indication obtained from the crossed-winding type of meter can, however, be made unidirectional by the addition of suitable components to the system.

If a nondirectional radio-wave pickup, such as that obtained from a "whip" or "T" antenna commonly used on aircraft, is combined in proper phase with the patterns of Fig. 2a for the crossed loops, the following results are obtained.[5]

$$E_a = E_{la}^{\max} \cos \theta + E_s \tag{6}$$

and

$$E_b = E_{lb}^{\max} \sin \theta + E_s \tag{7}$$

where E_a is the effective value of the loop voltage plus the sense voltage.

In the case where $E_{la}^{\max} = E_{lb}^{\max} = E_s$, the resulting pattern can be shown as in Fig. 3a. Now, if these voltages are applied to separate amplifiers, the rectified output voltages for various values of θ may be shown as in Fig. 3b. It is interesting to note that, by adding a sense voltage to each of the loop voltages, we have succeeded in amplifying and rectifying the loop-voltage components without change. That is, the rectification process does not affect the polarity of the loop voltages as long as the results of (6) and (7) are positive values.

We may now write the following equation of proportionality

$$E_A/E_B = E_a/E_b(E_{la}^{\max} \cos \theta + E_s)/(E_{lb}^{\max} \sin \theta + E_s) \tag{8}$$

where E_A and E_B are the rectified direct voltages. If the rectified voltages are considered to be made up of two components, as follows:

$$E_A = E_{LA}^{\max} \cos \theta + E_S \tag{9}$$

and

$$E_B = E_{LB}^{\max} \sin \theta + E_S \tag{10}$$

where E_S = the direct-current component resulting from the sense voltage

$E_{LA}^{\max} \cos \theta$ = the direct-current component resulting from the loop A voltage

$E_{LB}^{\max} \sin \theta$ = the direct-current component resulting from loop B.

Then, the value of E_S might be subtracted from E_A and E_B to allow the following expression to be written.

$$\frac{E_{LA}}{E_{LB}} = \frac{E_{LA}^{\max} \cos \theta}{E_{LB}^{\max} \sin \theta} = \frac{E_{la}^{\max} \cos \theta}{E_{lb}^{\max} \sin \theta} = \frac{E_{la}}{E_{lb}} \cdot \tag{11}$$

This gives us direct voltages which are proportional to the original loop voltages in amplitude and have the same relative polarities as the loop voltages for all values of θ.

The above results can be accomplished in practice in the following manner. First, an additional amplified sense voltage must be made available; and second, two additional windings must be incorporated in the indication device. Fig. 4 gives an illustration of the basic system. Windings C and D of Fig. 4 are wound with unity

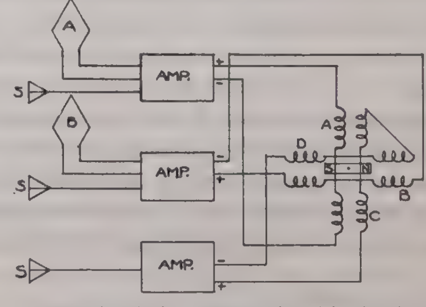

Fig. 4—Basic circuit for unidirectional indication with crossed-winding meter.

coupling to windings A and B respectively, and the voltage E_S is so applied as to cause the flux set up by these windings to oppose the flux set up by windings A and B. Now, if the angle ϕ is calculated, it is found to be equal to the angle θ. The magnetic armature is acted upon in such a manner as to seek an angle relative to the angle at which the incident wave is striking the loop assembly, and thus we have a visual indication of the bearing which will be unidirectional.

Three important factors must be kept in mind if the above results are to be achieved satisfactorily in

[5] Donald S. Bond, "Radio Direction Finders," McGraw-Hill Book Company, New York, N. Y., 1944, Chapter 5.

practice. The sense voltage must always be equal to, or greater than the maximum loop voltage, the gain of the three amplifiers must be equal, and the design must be such as to obtain linear-gain characteristics throughout the required operating range.

Receiver Development

The method of developing an appropriate indicator has been analyzed, but the problem of obtaining overall simplicity is far from being overcome. The system as described up to this point demands the use of three separate amplifier systems.

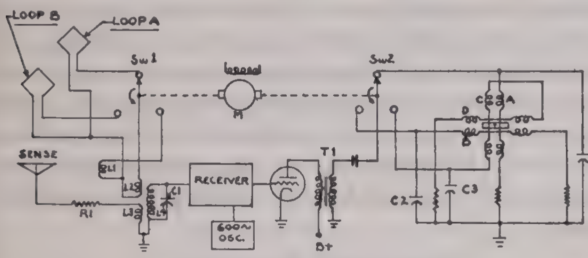

Fig. 5—Simplified circuit of automatic radio direction-finding system.

To simplify the system further, a single receiver must be made to do the work of the three described previously, and must do it with a minimum of auxiliary components. Another point not to be overlooked is the avoidance of circuits that require critical balancing in order to achieve satisfactory results. It is obvious that the three input voltages cannot be applied to the input of a single receiver simultaneously to obtain output voltages which would be of any value as far as this system is concerned. The possibility of applying the voltages successively to the input of the receiver by means of a pulsing method was investigated and found to be satisfactory.

Two receivers have been built, one using an electronic pulsing system and one using a mechanical pulsing system. In the interest of conserving space, and also because of the simplicity of the illustration, the mechanically switched receiver will be described.

Fig. 5 gives a simplified diagram of the circuit, and the following is a brief description of its operation. For illustration, let us assume the signal to be striking the forward edge of the loop A and let this be the reference point, or zero angle. The sense antenna is connected to $L3$ through $R1$ at all times. $R1$ is in the circuit to give the proper phase relationship between the sense and loop voltage. Motor M is connected to $Sw1$ and $Sw2$ so as to rotate their poles at a speed of approximately six revolutions per second. The desired signal is tuned in by means of $L4$ and $C1$ and the motor is turned on. Now, for the first 120 degrees of rotation of $Sw1$, loop A is connected to $L2$ and will apply a voltage in combination with the sense voltage to the receiver input which may be shown as E_a in Fig. 6 for θ equals zero degrees. As $Sw1$ is rotated through the second 120 degrees, loop B is connected to $L2$; therefore, a pulse is introduced into the receiver consisting of this voltage in combination with the sense voltage. For the case where θ equals zero, the loop B voltage is zero, and therefore only the sense voltage is applied to the input. This is shown in Fig. 6, for θ equals zero, as E_b. For the third 120 degrees of rotation of $Sw1$, the dummy-loop coil $L1$ is connected to $L2$. This is merely to keep the input properly loaded when the loops are switched out of the circuit. This last pulse consists of sense voltage only, and is shown in Fig. 6 as E_s. As stated previously, the cycle is repeated approximately six times per second.

The sequence of input voltages is amplified by the radio-frequency amplifier and converted to an intermediate frequency as in a conventional receiver. As the voltages pass through the intermediate-frequency stages, a 600-cycle component is added. This is done to insure a modulated output at the detector for all incoming signals. This modulation is necessary in this particular receiver, and will be discussed later.

The amplified and modulated signal voltages are then rectified and applied to the grid of a zero-biased amplifier, the output of which is fed through transformer T to the indicator rectifier. Here the output voltages are rectified and the resulting direct voltages are introduced into the rotor of $Sw2$. $Sw2$ is synchronized with $Sw1$ so that indicator winding A is connected to the output as loop A is connected to the input, and winding B is connected to the output as loop B is connected to the input. Windings C and D are connected to the output when the sense voltage only is applied to the input. It should be noted that windings C and D are so connected that their currents flow in opposition to the currents flowing through windings A and B.

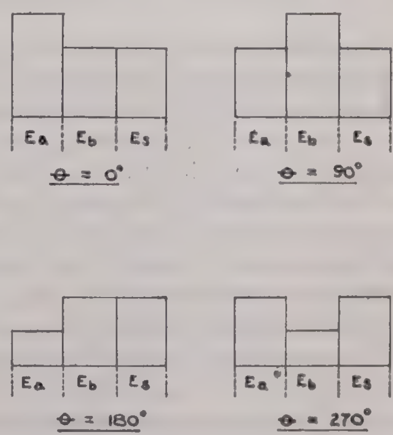

Fig. 6—Pulse input to receiver in the special case where $E_s/E_{la}=E_s/E_{lb}=2$.

The respective windings of the indicator each receive one pulse of rectified voltage per revolution of $Sw2$. Therefore, we have a pulsating direct current flowing through each winding that is a function of the switching frequency. In order to convert this pulsating current into a steady direct current, the windings are shunted

by the large filter capacitors $C2$, $C3$, and $C4$ (Fig. 5).

For the value of θ equals zero degrees, the fields set up by windings B and D cancel, and the fields of windings A and C are such as to cancel the portion contributed by the sense voltage, leaving only the field set up by the excess of current in winding A, due to the voltage of loop A, to act upon the armature. We will now call this the zero position of the armature. If the signal is striking the loop A on the rear edge where θ equals 180 degrees, the input pulses may be shown as in Fig. 6, for θ equals 180 degrees. By following the same line of thought as previously used, we find that once again the fields set up by windings B and D cancel, and that the resulting field set up by windings A and C is from the difference of the values of currents due to E_A and E_S. This leaves a field of the same amplitude as before, but of opposite polarity. This again agrees in direction with the voltage developed by loop A, and the armature will be displaced by an angle ϕ equal to θ. Examination of the resulting indicator fields for any angle of reception will show that the armature will indicate the true value of θ within the limits of the linearity of the component parts which make up the system.

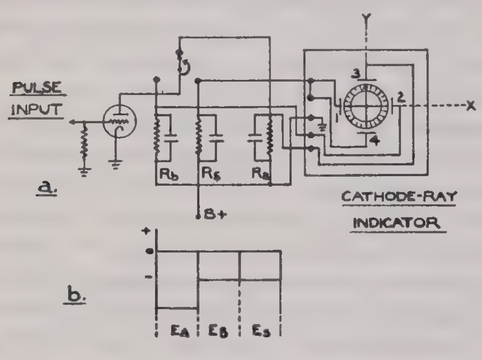

Fig. 7—Circuit arrangement of cathode-ray-tube indicator.

One of the requirements stated in the introduction was that of reliability of operation of the system. Therefore, some visual indication should be present that would assure the operator that the system is functioning normally when a signal is being received. Of course, this could be done by continual aural monitoring, but in practice this is not the most convenient method. In this system a visual indication of proper operation is included. Referring to Fig. 5, the input and output switching is carried on at a frequency that will cause a slight fluctuation in the resultant field set up by the currents flowing in the indicator windings. When a signal is tuned in, the intermediate-frequency component is modulated, and the resulting modulated pulses are passed through the output transformer to the indicator, which will seek the proper position and then continue to hunt or vibrate around this point. If the station to which the system is tuned should suddenly go off the air, no power would be supplied to the indicator, and the armature would immediately cease to hunt. Also, if the receiver should fail, the same nonoperating indication would be present, and a check could be made to determine the source of trouble.

Tests have been made on the completed receiver whereby the indicator windings were inserted directly in the plate circuit of an indicating tube, and the voltages developed by the input pulses were applied to the grid of this tube as a negative bias. In this case it is obvious that the 600-cycle modulation is not necessary, as either modulated or unmodulated signals would develop the operating bias for the indicator tube. The results obtained were satisfactory, but the hunting characteristics of the indicator were present at all times, regardless of the signal input. This was explained by the fact that tube plate current was flowing through the meter windings at all times, even though no pulse voltage was present on the grid. If filter condensers were chosen so as to give a slight ripple, and the tube operated at cutoff with no signal applied, the indicator armature could probably be made to have a desired hunting characteristic.

Electronic Indicator

An electronic indicator such as the cathode-ray tube would have advantages in some special installations. The writer visualizes the possibility of using one cathode-ray tube as a combined indicator for several functions, such as automatic direction finding, blind landing, and possibly an horizon indicator. With this in mind, experiments were carried out with a view towards developing such an indicator for the system herein described. Fig. 7 shows a possible circuit and an explanation of its operation follows.

As the train of voltage pulses, shown in Fig. 7b, is impressed on the grid of the indicator tube, a similar variation will be observed in the output voltage of this tube. Now, so that these pulses may be separated, the output section of the rotary switch is synchronized to connect each of the load resistors to the plate of the tube at the instant the plate current changes from one value to another. This gives three values of plate voltage across the respective load resistors which are designated as E_A', E_B', and E_S'. The voltages are completely filtered by relatively large capacitors. The load resistor Rs is connected to plates 1 and 4 of the cathode-ray tube. Ra and Rb are connected to plates 2 and 3 respectively. This effectively applies the voltages E_A' and E_B' to the plates of the indicator tube with E_S' as zero reference.

The next step is to adjust the electron stream of the cathode-ray tube until a small dot appears on the screen. Now, when the voltages on plates 1 and 2 are equal, a condition existing when the incident wave is striking the forward edge of loop A, the dot will be held in the center of the X axis. But, as has been pointed out previously, the voltage picked up on the loop A is at a maximum at this instant and is polarized so as to add to the sense voltage. Thus, due to the circuit arrangement, a voltage is applied to plate 3 that is more

positive than the voltage applied to plate 4, and therefore the dot moves up on the Y axis as indicated in Fig. 7a. The voltage values may be computed for various angles of wave reception to show that the results are such as to cause the dot to seek an angle with reference to the Y axis, which is equal to the angle of reception with reference to loop A.

By the use of automatic volume control, the signal strength of the received wave can be adjusted so as to keep the dot well out on the edge of the screen. This allows a more accurate reading to be taken on the bearing. In the case of a manual volume control, the distance from the dot to the center of the tube will give an indication of the received signal strength. This might be used to give an additional check on the operation of the system in cases where a homing maneuver is being executed. In such a case, the dot would fall on the upper portion of the Y axis, and by observing whether it progressed toward the center, or away from the center of the ray tube, as the homing course was continued, an indication of the true direction of the station is present.

As in the case of the mechanical indicator, the electronic type also gives a visual monitoring of the operation of the system, including the assurance of the presence of signal input. Should the dot suddenly come to rest in the center of the screen or shift erratically, the operator would be warned of malfunction and an investigation could be made to determine the trouble.

Conclusion

There are many features of this system that would make it suited for light airplane installations. A mechanically pulsed receiver, together with a mechanical type indicator might be made very compactly, and would be extremely simple to operate. One unit that has been constructed consists of a six-tube receiver, and the complete system has a total weight of under 25 pounds. However, this is an experimental model and this weight should not be taken as a final minimum.

Another interesting feature of the system is evident when the full advantages of the crossed-loop assembly are considered. Aural direction finding may be realized with the use of a goniometer of the conventional type. It is also possible properly to phase the loop voltages so as to obtain a null or "homing" pattern, and then, merely by reversing the polarity of one of the loops by a switch on the control panel, to obtain an antistatic "range" loop pattern. These latter type patterns are in much evidence on small aircraft, but in most cases are obtained by rotating manually a single loop to either its null or maximum pickup position. Some tests have been made and it seems entirely practical that the loop voltages can be phased so as to give nondirectional antistatic reception, which would be of great advantage to any type of aircraft radio installation.

It is feasible, by using the system herein described, to construct a dual automatic direction-finding installation with a minimum of component parts. For instance, if a six-point commutation were used, the same loop assembly and sense antenna might be used for both receivers, each of which would be tuned to a different frequency. The output thus obtained could be amplified through a common audio channel and then be separated for distribution to respective indicators for visual analysis. Or still another conservation of components might be realized by using a single cathode-ray tube as a dual indicator. This could be accomplished by switching the plates of the cathode-ray tube alternately from one to the other of two receivers. If the switching frequency is properly chosen, two dots will appear on the screen of the tube, each dot representing the bearing of the respective received signals.

It is realized that very precise engineering must be built into a system such as the one here described in order to obtain accuracy comparable to that of most systems now in use; however, by the use of a single receiver, to amplify the necessary voltages, an advantage is gained over other similar systems requiring three separate balanced receivers for proper operation. This is due to the fact that any minor voltage change or shifting of the tube characteristics will have an equal effect on all three input voltages, and will therefore have little effect on the accuracy of the system.

The material presented in this paper is based on laboratory experimentation and is, therefore, inadequate as far as definite predictions are concerned. However, the postwar period will surely demand a simple, light-weight, automatic direction finder, and a departure from the present-day design is inevitable if this demand is to be met.

Experimental Determination of Impedance Functions by the Use of an Electrolytic Tank*

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Summary—**It is shown that impedance and gain functions can be determined by the use of an electrolytic tank. The method is amply accurate and is rapid and convenient when the locations of the poles and zeros of the function to be determined are known. Full details of the theory are given, a suitable experimental setup is described, and typical results are shown.**

Introduction

THE FUNCTIONS giving the impedance of a network, the gain of an amplifier, etc., in terms of the frequency are often exceedingly complicated, making it a tedious process to produce plots of amplitude and phase by direct calculation from these functions.

The method to be described was devised to avoid this tedium by substituting for the slide-rule work a rather simple experiment using an electrolytic tank.

As will appear presently, the location of the electrodes in the tank depends on the positions of the various poles and zeros of the impedance or gain function in the complex frequency plane. The method is, therefore, convenient only when the pole and zero positions are easily found. This is the usual condition in amplifiers where the individual interstage-coupling networks are ordinarily quite simple, and the tubes cause the impedances of the networks to combine in a multiplicative manner. The saving in labor is especially great when there are a number of nonidentical stages. On the other hand there are cases in which the discovery of the pole and zero positions is difficult; in these cases, much of the effectiveness of the present method disappears.

In addition to possible savings in time, the procedure to be described has other important advantages; for it is based on an analogy between electrostatics and function theory, and thus the highly developed mechananism of potential theory becomes available for the solution of circuit problems. Similarly, the common and easily developed "feeling" for electrostatic problems may be applied to give useful qualitative results in circuit theory.

In what follows, then, we will give the needed theory and a brief description of some typical experimental results. The theory may be divided roughly into a general formulation of the problem, the introduction of suitable scale factors, the precise statement of the electrolytic-tank analogy, the methods of evaluating the various constants experimentally, and finally, methods of correcting for the finite size of practical tanks.

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Theory

As is well known, impedance Z is a rational function of the radian[1] frequency ω. It is, therefore, an analytic function of the *complex* variable ω and it is often useful to consider complex values of ω, even though experimental results usually apply only to real values of ω. The above is also true of the gain function of an amplifier $G(\omega)$, and since the present method seems likely to be most useful in connection with amplifiers, the notation, etc., will be chosen to facilitate application to amplifiers. The slight modifications needed for other applications will be quite apparent.

To proceed, then, the gain of an amplifier can be written

$$G(\omega) = a(\Pi(\omega - \omega_z)/\Pi(\omega - \omega_p)) \tag{1}$$

where the continued product in the numerator is over l zeros ω_z, and that in denominator over m poles ω_p. We note that the zeros and poles occur in pairs with symmetry about the imaginary axis.

Also, there is a relation between $m-l$ and the number of stages, which we shall call n. Thus let us assume that the plate of any tube and the grid of the following tube are connected together; i.e., that we have two-terminal coupling. Then the coupling impedance consists of a capacitance in parallel with an arbitrary impedance, the least possible value of this capacitance, which we shall call C, being the sum of the plate and grid capacitances. Now as $\omega \to \infty$ the capacitive admittance will dominate, and therefore the gain must decrease as $1/\omega$ for one stage, or for the whole amplifier as $(1/\omega)^n$, and so $m-l=n$. If the grid and plate capacitances are separated (four-terminal coupling) then $(m-l) \geqq 2n$. Our method works equally well in this case, and the slight modifications in notation needed will not be discussed.

To proceed further, we need to know the constant a, and it is also useful to introduce scale factors so that suitable dimensionless variables may be employed.

Thus we write the identity

$$G(\omega) = a\frac{\Pi(\omega - \omega_z)}{\Pi(\omega - \omega_p)} = G(0)\frac{a}{G(0)}\frac{\Pi(\omega - \omega_z)}{\Pi(\omega - \omega_p)} \tag{2}$$

with the idea of measuring gain in terms of $G(0)$, the gain at zero frequency. However, this gain, if evaluated from (1), also involves a, and therefore the second factor in (2) may be simplified by the introduction of a scale factor ω_0 defined by

$$\omega_0{}^n = \Pi|\omega_p|/\Pi|\omega_z| \tag{3}$$

[1] We use the time factor $e^{j\omega t}$. Those who prefer the e^{pt} notation may make the translation by writing $-jp$ for ω everywhere, and rotating all maps in the complex plane by 90 degrees.

whereupon
$$G = G(0)(-j\omega_0)^n \frac{\Pi(\omega - \omega_z)}{\Pi(\omega - \omega_p)} = G(0)(-j)^n \frac{\Pi(w - w_z)}{\Pi(w - w_p)} \tag{4}$$
where $w=\omega/\omega_0$; i.e., we measure frequency in terms of ω_0.

The above definition of ω_0 assumes that none of the ω_z is zero. Rigorously, there usually is at least one zero per stage at the origin because of the necessity of direct-current isolation of plate and grid as, for example, by blocking capacitors, mutual-inductance coupling, etc. Practically, these may usually be neglected. In the low-pass case the zero at the origin is accompanied by a pole a very short distance up the imaginary axis, and except at nearly zero frequency their effects cancel. In the band-pass case it is usually expedient, for other reasons, to adopt a new origin centered on the pass band, and to count the poles and zeros near this pass band but to neglect those near $\omega=0$ and near the negative pass-band frequency.

It is also useful to write G and ω_0 in terms of various circuit constants and, incidentally, to give an interpretation to ω_0. Plainly, the needed constants are the g_m of the tube, and some two constants of the coupling network. These latter two are most simply taken as C, which controls the gain at $\omega\to\infty$ and R, the resistive impedance of the coupling network for direct current, which controls the gain at $\omega=0$. Then R determines $G(0)$ as $(g_mR)^n$ and the product RC establishes a time scale. As to this time scale, we can write the a of (1) either as $(-jg_mR\omega_0)^n$ from (4) or as $(-jg_m/C)^n$ by consideration of the behavior of (1) at $\omega\to\infty$. Comparing the two expressions we see that $\omega_0=1/RC$. Also, one may write $G(0)$ in terms of C and ω_0 instead of R, thus obtaining $G(0)=(g_m/C\omega_0)^n$.

In computing the gain-bandwidth product, the fact that altering R changes $G^{1/n}$ and the frequency equally and in opposite directions is easily utilized by the employment of these variables. Specifically, if the bandwidth is found to be w_0, the gain-bandwidth product is $(g_m/2\pi C)w_0$.

All of the above tacitly assumes that R is the same for all stages. Often this is not true, in which case we simply take R to be the geometric mean of the various coupling resistances.

One further transformation that is often useful introduces a normalized gain $g(\omega)=G(\omega)/G(0)$, thus measuring gain in terms of the zero-frequency gain. Also, it is sometimes convenient to consider $g^{1/n}$ which is the stage gain if the stages are identical and a sort of mean stage gain if they are not.

Having disposed of the above preliminaries, we may begin on the main problem by remarking that we usually want not the real and imaginary parts of G but the absolute magnitude and the phase thereof. The separation in this form may be achieved by taking the logarithm. Thus
$$\log|G|=\log|a|+\sum\log|\omega-\omega_z|-\sum\log|\omega-\omega_p| \tag{5}$$
and
$$\arg G=-n\pi/2+\sum\arg(\omega-\omega_z)-\sum\arg(\omega-\omega_p). \tag{6}$$

Now (5) at once suggests potential theory. Specifically, if we put l equal negative line charges at positions corresponding to the zeros and m similar positive charges at the poles, the resulting potential distribution on a plane normal to the line charges would correspond, with suitable choice of constants, to the amplification function $|G|$ on the ω plane. Also, it is well known that, if we plot the equipotential lines and then construct an orthogonal set of curves, then this orthogonal set will correspond to the lines of constant arg G.

There is nothing new in the above, of course. In less specific form it has probably been stated in every complex-variable course ever given. Nor is there anything new in the additional remark that one may equally well use, in forming the analogy, the current flow in a uniform two-dimensional medium, for example, an electrolytic tank.

But, surprisingly enough, it has not become common practice to exploit this analogy. We wish to suggest here that the analogue is a useful one, and to give instructions for its experimental realization.

The two main questions that arise are the following. First, how do we arrange the apparatus and reduce the experimental data in order to get the proper values of the various constants; and second, what is the effect of using a tank of finite size as must, of course, be done in practice?

As to the first question, we note that there must be two free constants, since we certainly need a scale factor to convert the measured voltage in volts to gain in nepers; and we also need to specify the zero of potential. These constants are easily fixed, as follows. If the measured voltage be called V and we wish to find $\log|g|$ we must divide by a constant, call it V_0, such that, as $r\to\infty$ V/V_0 will vary as $(m-l)\log|r|$ as $\log|g|$ varies; and then we must add a constant chosen so as to give $g(0)=1$.

The constant V_0 is most easily determined by making an auxiliary experiment in which a single probe, corresponding to a single pole, feeds current into the electrolytic tank. No error will arise due to finite tank size if it is bounded by a circle centered on the wire or probe. The potential is measured as a function of radial distance from the probe. We then plot this potential V against $\log|r|$, whereupon we should obtain a line whose slope we shall call V_0. Plainly enough, then, if V be measured for some other arrangement of probes, i.e., poles and zeros, the quantity V/V_0 will be similar to $(m-l)\log r$ at infinity and therefore will correspond to $\log|g|$.

As to the second constant we have only to choose our zero of potential to be the potential at the origin. This makes $V/V_0=0$ at $w=0$ which is correct, since $|g|=1$, $\log|g|=0$.

Thus, if we measure potential difference between any point and the origin and call it V and divide this by V_0, as determined in the above-described experiment, then the quantity V/V_0 will be identical with $\log |g|$.

We come now to the question of the effect of the use of a finite tank which we will take to be of circular form with the circle centered on the origin. The needed results are easily found from standard results of potential theory.

Thus, if we take (5) and express the various logarithms appearing in terms of the well-known expansion of $\log r_{12}$ we find

$$\log |g| = \sum \log |w - w_z| - \sum \log |w - w_p|$$
$$= (l - m) \log r - \sum \frac{a_k}{r^k} \cos k\theta - \sum \frac{b_k}{r^k} \sin k\theta \quad (7)$$

where r and θ are polar co-ordinates in the w plane, as is illustrated in Fig. 1, and the summations are over k. Here

$$a_k = \frac{1}{k} \left[\sum r_z{}^k \cos k\theta_z - \sum r_p{}^k \cos k\theta_p\right] \quad (8)$$

$$b_k = \frac{1}{k} \left[\sum r_z{}^k \sin k\theta_z - \sum r_p{}^k \sin k\theta_p\right] \quad (9)$$

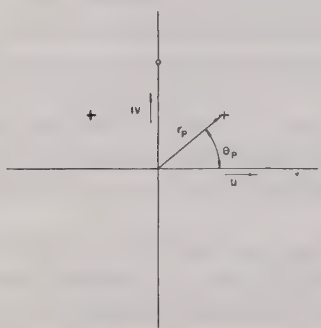

Fig. 1—Location of a point in the $w = u + iv$ plane shown in this figure is determined by co-ordinates u and iv. Also used are polar co-ordinates r and θ which are illustrated defining the position of the pole indicated by a cross, a zero being designated by a circle.

with r_z, θ_z and r_p, θ_p the polar co-ordinates of the various zeros and poles and with the summation over p and z. The expansion is valid only when r is larger than the radius corresponding to the pole or zero most distant from the origin. Other expansions can be written for other ranges of r but are not of interest at the moment.

Since impedance functions always have poles and zeros symmetrically distributed about the imaginary axis, it follows that only the even a_k and the odd b_k are nonzero. Moreover, since one wants only $|g|$ on the real axis, and the sine terms are zero there, we see that in using this series to find $|g|$ only the even cosine terms survive.

The above gives the value of $\log |g|$ and also the value of V/V_0 that would be found in an infinite electrolytic tank with electrodes corresponding to the poles and zeros and with each electrode carrying a current equal in magnitude to that used in determining V_0.

But in a tank of finite radius, which we shall call r_0, we must subtract from (7) a potential function which satisfies Laplace's equation, has no singularities inside r_0, and makes the potential constant on the circle $r = r_0$. If we call this subtracted function ΔV it is plain that

$$\log |g| = 1/V_0[V(\text{measured}) + \Delta V] \quad (10)$$

and hereafter we shall denote the measured value of V by V_m. The form of ΔV is obtained by standard methods of potential theory from the above specifications; so we have

$$\log |g| = \frac{V_m}{V_0} - \sum a_k \frac{r^k}{r_0{}^{2k}} \cos k\theta - \sum b_k \frac{r^k}{r_0{}^{2k}} \sin k\theta \quad (11)$$

or on the real axis

$$\log |g| = \frac{V_m}{V_0} - \sum a_k \frac{r^k}{r_0{}^{2k}}. \quad (12)$$

For reasons to be explained later, the derivative of $\log |g|$ in the imaginary direction is also of interest and on the real axis this has the value

$$\frac{d \log |g|}{dv} = \frac{1}{V_0}\left(\frac{dV_m}{dv}\right) - \sum kb_k \frac{r^{k-1}}{r_0{}^{2k}}. \quad (13)$$

As to the corrections arising from finite tank size, two things can be done. First, by making the tank large, the corrections may be made small or even negligible. Second, we may, if necessary, apply the corrections. In this connection it is important in principle to understand that after the corrections are applied the results are exact, regardless of tank size. That is, decreasing the tank size does not change the attainable accuracy, which is always perfect, but merely requires use of more terms in the correction formula. Practically, of course, one uses a tank large enough to make the corrections small, for if many terms in the series for ΔV must be used, the main advantage of our method, its simplicity, disappears.

Ordinarily, there is little difficulty in making the corrections small, as may perhaps be well illustrated by an example. Consider a single resistance-capacitance coupled stage which gives a single pole unit distance up the imaginary axis. Then all nonzero a_k and b_k have numerical value $1/k$. The tank we have used has $r_0 = 8$. Thus at $r = 8$ the first nonvanishing term in the series on the right of (12) is 1/128 for $k = 2$ and the next is 128 times smaller. So if we omitted the correction entirely the error in $|g|$ would be about 1 per cent. Thus it is not hard to make the first term rather small, and if we do this, following terms are certainly negligible. Moreover, the correction becomes smaller quadratically as we go in from the edge of the tank.

Although the corrections can be made small, and are very easy to apply when the a_k and b_k are known, some simplification in the methods of finding these coefficients would be of help. They can be found rapidly, as follows. We note first that only b_1 and a_2 are ever of practical significance, and that, since the total correction is small, no great percentage of accuracy is required in computing the coefficients. We can therefore obtain sufficient accuracy by using contour maps of the functions $r \sin \theta$ and $(r^2/2) \cos 2\theta$ to evaluate b_1 and a_2 by (8) and (9).

The lines $r \sin \theta$ = constant are, of course, simply straight lines parallel to the real axis, and this seems too simple to justify a figure. The second function is illustrated in Fig. 2, where it will be seen that the contour lines are hyperbolas, as may easily be shown directly. To use such a map to find a_2 one simply locates the zeros and poles on the map and adds corresponding values read from the contours, using positive signs for zeros and negative for poles. In this way b_1 and a_2 may be evaluated rapidly and with more than sufficient accuracy.

We turn now to the question of determining the phase. We have found three methods of doing this and will describe each of them, although the first two are more instructive than practical. The third method appears to be quite satisfactory, and the first two will merely be sketched, many details being omitted.

According to the first method we observe that since $\log |G|$ is an analytic function of ω the lines of constant $\phi = \arg G$ must be everywhere orthogonal to the lines of constant $\log |G|$. We therefore plot contours of $\log |G|$ as explained above, except that now we must cover the whole plane instead of merely the real axis. Lines orthogonal to these contours are then drawn in and, if suitably spaced, these lines give the values of ϕ. The disadvantages are that determining a complete map of $\log |G|$ is tedious work and that the accuracy of constructing the orthogonal lines is open to doubt unless complicated calculations are introduced.

To proceed according to the second method, one first connects the various zeros and poles by a series of curves, each of which goes in the direction of the electric field. At each pole or zero two of these lines intersect: the angle of intersection is to be 180 degrees. The shape of these lines is found either from the electrolytic tank or from a rubber model. We then bend strips of metal to correspond to these lines and use these strips as electrodes which set up a new problem in the electrolytic tank. At each pole or zero there will be a gap between two strips. Across each gap we place π volts with the right-hand side positive for a zero, and vice versa for a pole. The effect is to set up a new potential problem in which lines of potential and lines of force are interchanged. The lines of constant ϕ then become equipotentials and ϕ can be measured directly. This method is probably less work than the first, but its accuracy is doubtful as it would seem to depend on having the electrodes of the right shape, which takes us back to the first method.

According to the third method we determine $d\phi/du$ first and then find ϕ by an integration. This sounds tedious but actually is not, since the "integration" can be a simple summation. As a whole, the method seems quite satisfactory because (a) for many purposes $d\phi/d\omega$ is the quantity actually desired; (b) the integration is not difficult; and (c) the integration introduces at least as great a degree of accuracy.

To determine $d\phi/du$ we note that since $\log |G| + j\phi$

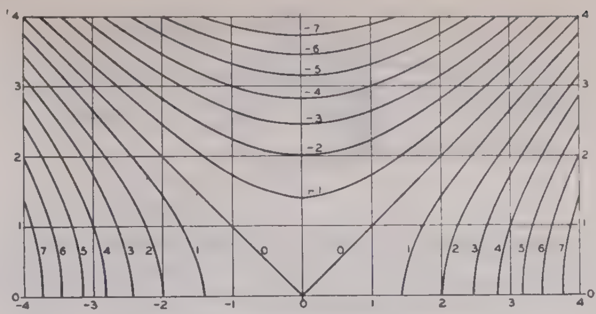

Fig. 2—Plots of $(r^2/2 \cos 2\theta = (u^2 - v^2)/2$ = constant. For use in evaluating a_2.

is an analytic function of $w = u + jv$ there is a relation between $\partial\phi/\partial u$ and $\partial \log |g| / \partial v$. The latter quantity is then easily determined experimentally.

The needed relation is easily found directly from one of the Cauchy-Rieman equations. Thus we have

$$\partial\phi/\partial u = \partial \log g/\partial v. \qquad (14)$$

Experimentally we can measure the difference in potential $\Delta_1 V$ between two probes spaced a distance Δv whereupon

$$\partial\phi/\phi u = \Delta_1 V / V_0 \Delta v. \qquad (15)$$

Finally, if we wish ϕ we can conveniently make the integration element equal to Δv. Then

$$\phi(k\Delta v) = \frac{1}{V_0} \sum_{0}^{k-1} \Delta_1 V \qquad (16)$$

where the $\Delta_1 V$ are observed at $u = \Delta v/2$, $3\Delta V/2$, etc. Starting at $\phi = 0$ at $u = 0$, ϕ will reach $(m-l)\pi/2$ at $u \to \infty$.

The absolute values of the residues at the various poles may also be found without difficulty, although they are not of great interest from the present point of view.

Perhaps the best procedure is to open the circuit to the probe corresponding to the pole in question and then measure the value of the potential on the probe. This potential is reduced in the same way as $\log |G|$ value is obtained by dividing by V_0 and subtracting a suitable constant. The result is then the log of the absolute value of the residue.

The same result may be obtained, in principle, by leaving all probes connected and measuring the potential of one of them. From this is subtracted the previously determined potential of a single probe fed with the same current. The resulting voltage is then treated as described above. The last method is probably not very satisfactory in practice, because the two measured voltages will be nearly equal, and therefore the loss of accuracy due to subtraction will be severe.

No simple method of electrically determining the arguments of the residues is apparent.

Experiment

We have experimented with the above-suggested procedure, obtaining results which will now be described briefly.

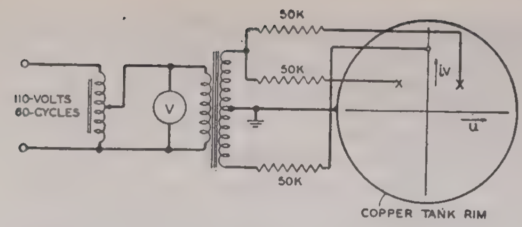

Fig. 3—Diagrammatic representation of apparatus for measuring g by means of an electrolytic tank. The arrangement of probes shown corresponds to the two poles and one zero characteristic of the common shunt-peaking circuit.

The apparatus is shown diagrammatically in Fig. 3. The electrolytic tank is circular, of eight-inch radius, and having the rim and all other electrodes of copper, the electrolyte being a dilute-copper-sulphate solution. The electrolyte is about $\frac{3}{8}$ inch deep and, with the concentration used, the impedance of one probe is a few hundred ohms. The probes corresponding to the poles and zeros are supplied with current from the opposite ends of an ordinary plate-supply transformer with grounded center tap. In series with each probe is a 50,000-ohm resistor. Voltages are measured with a Hewlett-Packard vacuum-tube voltmeter having an input resistance of two megohms. A variac and primary voltmeter maintain constant input.

The first procedure is to measure V_0. To do this one, probe is put at the origin and the voltage on the u axis measured as a function of u. The voltage is plotted against log u and the slope gives V_0. Two representative plots are shown in Fig. 4.

It will be seen that this plot is accurately linear. It should also be noted, however, that the end point, corresponding to the tank radius, does not fall on the straight line. This is also true of the point corresponding to the probe radius, though this point is not shown on the graph. This deviation indicates an electrode effect of some sort. We have not investigated this at all since its presence can have no effect on our method, provided the electrode whose potential is being measured carries substantially zero current, as is, of course, the case when using a vacuum-tube voltmeter.

Next, one measures V for an arrangement of probes corresponding to the location of poles and zeros in the gain function desired. Two points arise here.

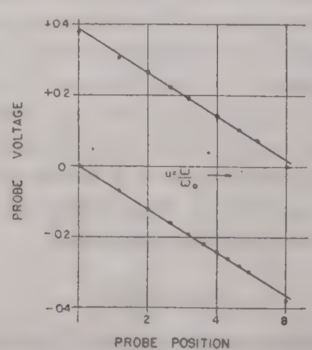

Fig. 4—Plot of probe voltage versus log of radius as used in determining V_0.

In the first place, we note that, by placing a second set of probes below the real axis in positions that are mirror images of those above, we can practically eliminate errors due to the measuring probe not being exactly on the real axis. This precaution seems well worth while. To illustrate this by example, suppose we are measuring $|g|$ for a single resistance-capacitance coupled stage, which corresponds to a single pole at $v=1$. Then if we use only this one pole a displacement of the measuring probe by only 0.010 inch (for one inch $=$one unit of v) will give a 1 per cent error in $|g|$. If, on the other hand, we introduce an image pole at $v=-1$ the error due to 0.010 inch displacement is $\frac{1}{2}\times 10^{-4}$. Or, to put it in another way, a displacement of 0.14 inch is required to give an error of 1 per cent. Thus, the use of a set of images reduces the requirements on the slider carrying the measuring probe from fairly severe to quite negligible. Of course, the extra set of poles and zeros doubles the voltmeter readings.

TABLE I

Sample Data
Determination of Amplitude

u	V_m	V_m/V_0	$2.41\,u^2/r_0^2$	V/V_0	$\|g\|=\epsilon^{V/V_0}$
0	0	0	0	0	1.000
0.5	−0.0010	−0.0058	+0.0001	−0.0057	0.994
0.75	−0.0045	−0.0262	+0.0003	−0.0259	0.974
1.00	−0.0120	−0.0698	+0.0006	−0.0692	0.933
1.25	−0.0245	−0.1425	+0.0009	−0.1416	0.869
1.50	−0.0415	−0.2410	+0.0013	−0.2397	0.786
2.00	−0.0820	−0.477	+0.0024	−0.475	0.622
2.50	−0.1230	−0.715	+0.0037	−0.711	0.491
3.00	−0.155	−0.901	+0.0053	−0.896	0.393
4.00	−0.213	−1.238	+0.0094	−1.229	0.292
5.00	−0.255	−1.483	+0.0148	−1.468	0.230
6.00	−0.293	−1.705	+0.0213	−1.684	0.186

The other point relates to the choice of the zero of potential. The most convenient thing to do is to connect the ground side of the voltmeter to the tank edge. The difficulty is that, since the percentage of error in the voltmeter readings is approximately constant, the absolute error is relatively large near the origin and small near the tank edge. Then, when the exponential is taken, we find ourselves knowing $|g|$ very accurately for large u and rather poorly near $u=0$. This is just the reverse of the usual order of interest. It is therefore obviously suggested that the "ground" end of the voltmeter be connected to a potential divider across one side of the transformer and adjustments made such that the voltmeter reads zero when the probe is at the origin. We have actually done this but have found, in our setup, that a zero voltmeter reading could not be obtained simply by adjusting the potentiometer. No doubt this could be remedied by careful shielding but we found it satisfactory to add two capacitors, one from the low side of the voltmeter to ground, and one across the voltmeter itself. These capacitors are adjusted by trial. At first sight such pickup may seem surprising in view of the low impedance offered by the probe. But it must be remembered that the voltmeter is expected to read down to around 10^{-3} volt while there are 250 volts present on the wires leading to the probes. (The probes themselves carry only a volt or so, most of the voltage

being lost in the 50-kilohm resistors which insure constant current.)

The results of a typical measurement are shown in Table I. These results are for a shunt-peaked amplifier with $L=0.414R^2C$ which gives the flattest amplitude response. This corresponds to a zero at $v=2.42$ and two poles at $u=\pm 0.98$ and $v=1.21$. This table shows measured values of V_m, the resulting V_m/V_0, the correction which comes out at $2.41u^2/r_0^4$, the resulting $\log|g|$ and finally $|g|$. The value of V_0 was 0.172. These results are given graphically in Fig. 5 where the points are experimental data and the curve is from the theoretical formula. It will be seen that the agreement is quite close.

To measure $d\phi/du$ we must, first of all, reverse the polarity of the connections to the "image" poles and

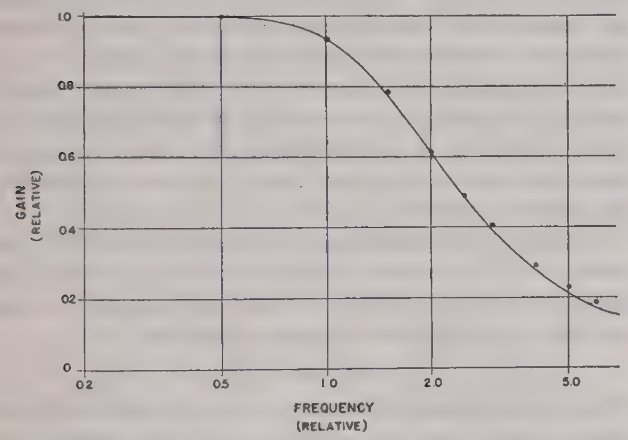

Fig. 5—Gain versus frequency of a shunt-peaked amplifier. $L=0.414\ R^2C$. —— calculated values; ····· experimental values.

zeros below the real axis. This makes the potential an odd function of v so that the measurements of dV/dv are only slightly affected by displacement in the v direction. The measured value of dV/dv will, of course, be doubled by the addition of the images.

Second, we must provide a pair of probes spaced at a fixed distance Δv and capable of motion along the u axis. Moreover, instead of measuring the voltage between these probes directly, it is convenient to connect the ground end of the voltmeter to the tank rim, which is at zero potential, measure the potentials of the two probes separately, and then add.

A complete set of data and its reduction are tabulated in Table II. In this case Δv was 0.52, $V_0=0.179$ and the setup, as before, was to represent the case of a shunt-peaked amplifier. For this particular case b_1 is identically zero so no tank correction is required. The results are also presented graphically in Figs. 6 and 7, where $d\phi/du$ and ϕ are plotted as functions of u. It will be seen that the agreement between theory and experiment is satisfactory. It should be pointed out that, to achieve such agreement, some care must be used in measuring Δv. Thus if, as here, $\Delta v=\frac{1}{2}$ inch the probe spacing must be measured to 0.005 inch to get 1 per cent accuracy. This is easily possible with a traveling microscope but for most purposes it would probably be simpler and just as satisfactory, or possibly more so, to adjust Δv to give the known proper value of $\phi=\pi/2$ at $u\rightarrow\infty$.

TABLE II

Sample Data
Determination of Phase Shift

u	$\Delta_1 V_m$	$\Delta_1 V_m/V_0$	$\Delta\phi$	$\frac{\Delta\phi}{\Delta u}$	$\phi=\Sigma\Delta\phi$
0					
0.25	0.0255	0.143			
0.50			0.273	0.546	0.273
0.75	0.0301	0.168			
1.00			0.322	0.644	0.595
1.25	0.0288	0.161			
1.50			0.308	0.616	0.903
1.75	0.0201	0.122			
2.00			0.215	0.430	1.118
2.25	0.0122	0.068			
2.50			0.131	0.262	1.249
2.75	0.0072	0.040			
3.00			0.077	0.154	1.326
3.25	0.0046	0.026			
3.50			0.049	0.098	1.375
3.75	0.0030	0.017			
4.00			0.032	0.064	1.407
4.25	0.0020	0.011			
4.50			0.021	0.042	1.428
4.75	0.0013	0.007			
5.00			0.014	0.028	1.442
5.25	0.0008	0.004			
5.50			0.009	0.018	1.451

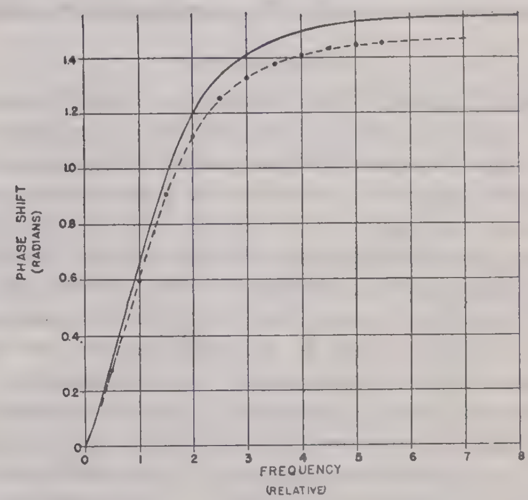

Fig. 6—Phase shift versus frequency of a shunt-peaked amplifier. $L=0.414\ R^2C$. —— calculated values; ·—·—· experimental values.

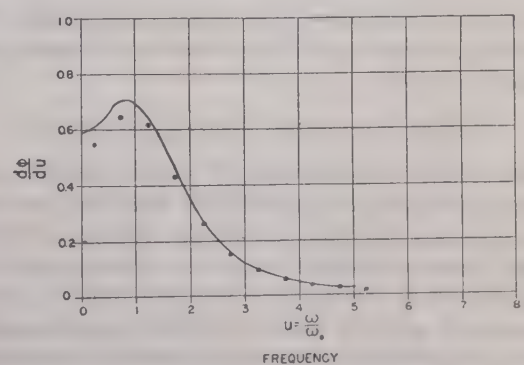

Fig. 7—$d\phi/du$ versus frequency of a shunt-peaked amplifier. $L=0.414\ R^2C$. —— calculated values; ····· experimental values.

CONCLUSION

In conclusion, it is our belief that the method described and illustrated above is a rapid and adequately

accurate method of evaluating gain functions when, as is usual, the location of the poles and zeros is easily found. Even more useful, to us, has been the new point of view coming with the introduction of the electrostatic problem, for a number of new and useful circuit-theory results have been suggested by well-known ideas in potential theory. Some of these we hope to describe at a later date.

Multivibrator Circuits*

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ANDREW F. INGLIS‡, ASSOCIATE, I.R.E.

Summary—**A simplified method is presented for the calculation of the voltage wave forms of nonsinusoidal voltage generators in which the circuit action is dependent upon the exponential charging and discharging of capacitors. A number of multivibrator circuits are then discussed and analyzed in accordance with this method.**

Introduction

THE ADVENT of television and allied communication systems has brought into use a large number of electronic nonsinusoidal voltage generators of which the most important is probably the multivibrator. Because the wave forms encountered in these circuits are not sinusoidal, and because the grid-voltage variations are so great that the tube seldom acts as a linear amplifier, conventional methods of circuit analysis are of little value. In the multivibrator, as well as in many other nonsinusoidal voltage generators, the wave forms must be calculated by the methods of transient analysis, and the vacuum tube can be most accurately represented as a resistor in series with a switch. As an introduction to the study of multivibrators, this paper presents a simple method of resistance-capacitance circuit analysis and a discussion of the representation of a vacuum tube by a resistor and switch. These methods are then applied to a number of typical multivibrator circuits.

The Resistance-Capacitance Circuit

The voltage variations in all circuits which contain one capacitor and any number of resistors and sources of direct-current potential always follow exponential curves. Three quantities fix these curves uniquely: the voltage at any time, the time constant resistance-capacitance, and the voltage which the exponential is approaching. If these three are known the entire curve can be drawn. In one time constant the voltage rises (or falls) approximately 63 per cent of the way between its value at the beginning of the time constant and the value which it is approaching. This is true of any part of the exponential curve. The curve, therefore, gets closer and closer to the value which it approaches but, from a mathematical standpoint, never reaches it. From an engineering standpoint, however, the difference eventually becomes so small as to be negligible. In four time constants the voltage rises (or falls) more than 98 per cent of the way between its initial value and the value which it is approaching. For many purposes, therefore, the voltage may be said to have reached an equilibrium value after four time constants.

The equations describing exponential curves are quite simple. If it is desired to know how long it takes the voltage to change from one value to another, the time can be found from the following equation

$$t = RC \log_\epsilon E_A/E_B. \tag{1}$$

E_A is the difference between the voltage at the beginning of the interval and the voltage which the exponential is approaching. Similarly, E_B is the difference at the end of the interval. These are illustrated in Fig. 1. Note

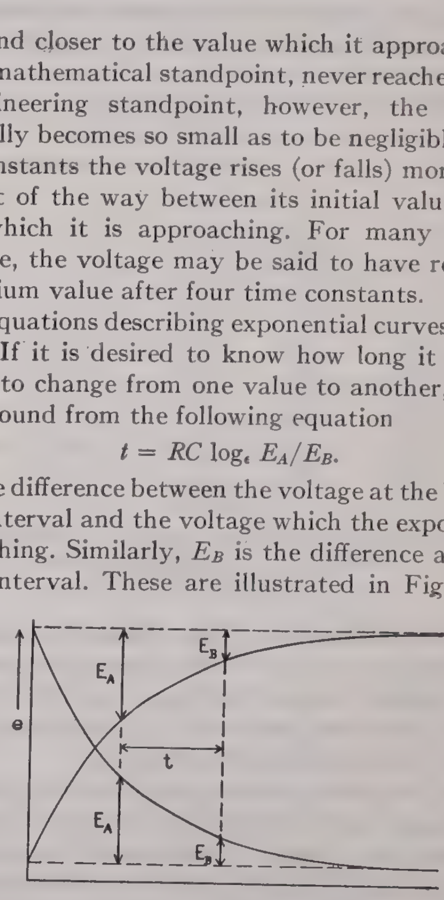

Fig. 1—Relationships on exponential curves.

that it is equally applicable to rising and falling exponentials. Equation (1) can also be written in exponential form if t and E_A are known and it is desired to find E_B

$$E_B = E_A\epsilon^{-t/RC}. \tag{2}$$

The technique of solving transients in resistance-capacitance circuits is summarized in the following three rules.

Rule 1: When a sudden change occurs in a resistance-capacitance circuit containing one capacitor and any number of resistors, the voltage between any two points in the circuit can be plotted by determining the voltage between the points just after the change occurs, the voltage between the points after the circuit again reaches equilibrium, and connecting these points with

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an exponential curve having the proper time constant. The time constant can be found by reducing the network connected to the terminals of the capacitor to a Thevenin generator. The product of the resistance of the generator and the capacitance of the capacitor is the time constant.

Rule 2: To determine the voltages in the circuit just after the sudden change, find the voltage across the capacitor just before the change. Because of the fact that the voltage cannot change instantly across a capacitor, to find the other voltages in the circuit is a simple direct-current problem.

Rule 3: Equilibrium conditions can be determined by considering the capacitor to be an open circuit.

The application of these rules to the equivalent circuit of a multivibrator is shown in Fig. 2. Assume that at t_1 switch 1 has been open and switch 2 closed a long

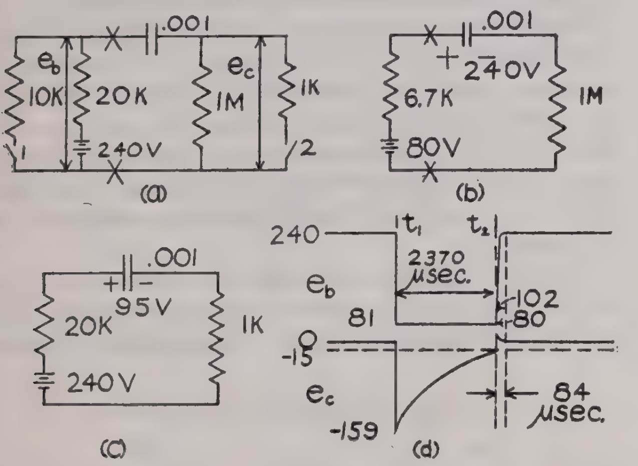

Fig. 2—Determination of the output wave forms of a resistance-capacitance circuit.
(a) Circuit.
(b) Equivalent circuit at t_1; switch 1 has just closed and switch 2 opened.
(c) Equivalent circuit at t_2.
(d) Wave forms.

time. The switch positions are then reversed. Evidently the capacitor is charged to 240 volts, and this will not change as the switch positions are reversed. If the portion of the circuit to the left of $X-X$ in Fig. 2(a) is reduced to a Thevenin generator, the equivalent circuit shown in Fig. 2(b) is obtained. The voltages e_b and e_c can be determined easily as 81 and -159 volts respectively. Evidently e_b will relax toward 80 volts and e_c toward zero volts as the capacitor discharges. The time constant is approximately: (1,007,000) (0.001 microfarad) = 1007 microseconds. Assume that when e_c has relaxed to -15 volts (equivalent to the grid of a multivibrator reaching cutoff) switch 1 opens and switch 2 closes. The time required for e_c to rise to -15 volts can be determined from (1).

$$t = 1007 \log_e 159/15 = 2370 \text{ microseconds.}$$

The capacitor has now discharged to 95 volts. Since the $1K$ resistor is now in parallel with the $1M$, the effect of the latter can be ignored and the equivalent circuit is shown in Fig. 2(c). By inspection it can now be determined that e_b has jumped to 102 volts and e_c to 7 volts. As the capacitor recharges, e_c will relax to zero and e_b to 240 volts. The time constant is 21 seconds, and in 4 time constants this relaxation will be substantially complete.

The Vacuum Tube As a Switch

In a large number of nonsinusoidal generators the grid voltage alternates between two values, one of which is below cutoff and the other in the conducting region, usually zero. Under these conditions the tube can be represented as a switch in series with a resistor and battery. Suppose, for example, that the grid voltage of the tube shown in Fig. 3(a) is held constant at -5 volts.

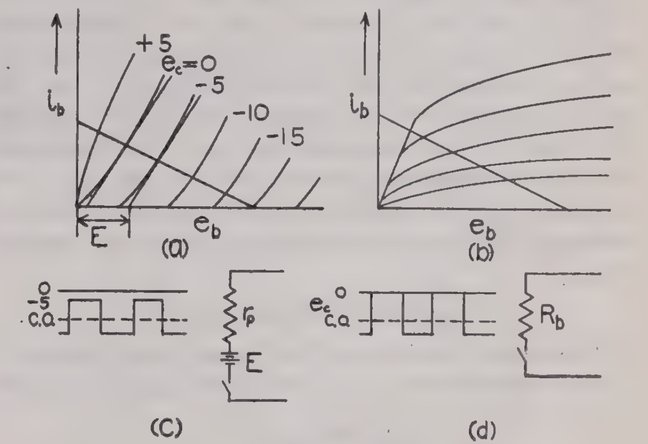

Fig. 3—Vacuum-tube plate characteristics and equivalent circuits.
(a) Typical triode characteristic.
(b) Typical pentode characteristic.
(c) and (d) Grid wave forms and corresponding equivalent circuits for triode.

Then the tube appears to external circuits as a resistor r_p, in series with a voltage E. E is determined by drawing a tangent to the curve of constant grid voltage at the point where it crosses the static load line and finding where it intersects the voltage axis. (See Fig. 3(a).) This equivalent circuit is quite accurate provided that the plate voltage does not vary too much from the value determined by the intersection of the static load line. When the grid voltage is below cutoff, the tube is evidently an open circuit. Thus, if a square wave is applied to the grid which alternates between -5 volts and any value below cutoff, the behavior of the tube can be predicted by alternately opening and closing the switch. This is illustrated in Fig. 3(c).

When the grid voltage of a triode is zero (or positive) the tangent intersects the voltage axis approximately at zero. Furthermore, the dynamic plate resistance is approximately equal to the static or direct-current value R_b. Without making a serious error, therefore, the tube can be represented by a resistor R_b and switch which is open when the grid voltage is below cutoff and closed when the grid voltage is zero. This is shown in Fig. 3(d).

With pentodes, a similar method can be followed. When the pentode is operating above the "knee" of the characteristic curves, the tangent to the characteristic intersects the voltage axis at a large negative voltage. The equivalent circuit of the tube is, therefore, a very large resistance r_p, in series with a very large battery, the positive pole of which is at cathode potential. If the tube is operating below the knee of the curves, the pentode has the properties of a rather small resistance. (Typical values: 6SJ7 = 3000 ohms, 6AC7 = 3000 ohms, 6AG7 = 800 ohms.)

The wave forms of the multivibrator are greatly affected by grid conduction, since this puts a heavy load on the plate circuit of the tube which drives the grid. When the grid is positive there is a reasonably linear relationship between grid voltage and grid current, the ratio for most small receiver-type tubes ranging from 500 to 2000 ohms. Thus the grid can be represented by a resistor and switch, the switch being open when the grid is negative and closed when the grid is positive. The exact value of this resistor makes little difference in the circuit calculations so long as it is of the right order of magnitude. It is usually safe, therefore, to assume a value of 1000 ohms as the grid resistance while conducting.

The Basic Multivibrator

The circuit, equivalent circuit, and wave forms of a typical multivibrator are shown in Fig. 4. It can readily

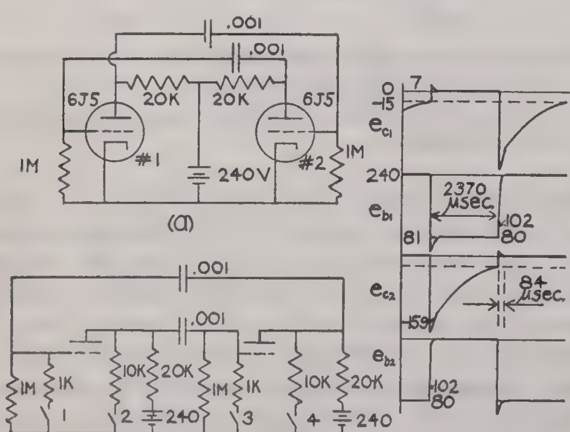

Fig. 4—Basic multivibrator circuit and wave forms.
(a) Multivibrator.
(b) Equivalent circuit; at t_1: switches 1 and 2 close, switches 3 and 4 open; at t_2: switches 1 and 2 open, switches 3 and 4 close.
(c) Wave forms.

be seen from the wave forms that the grid voltage is always either at zero or below cutoff with the exception of the short positive "pip" at the beginning of each cycle. This is a case, therefore, where the tube should be represented by a resistor and switch. A 20,000-ohm load line intersects the characteristic for $e_c = 0$ at $e_b = 80$ volts and $i_b = 8$ milliamperes. This gives $R_b = 10K$. Likewise, the grid can be represented by a 1000-ohm resistor and switch.

The cycle of operation is as follows. Consider the conditions in the circuit just before t_1. The grid of Tube 1 is just approaching cutoff, and the plate is at the supply potential. The grid of Tube 2 is at zero, and its plate is at 80 volts, due to the heavy flow of plate current. In the equivalent circuits, then, switches 1 and 2 are open and 3 and 4 are closed. When the grid of Tube 1 reaches cutoff, plate current starts to flow, dropping the plate voltage. This pulls down the grid of Tube 2 and thus causes its plate voltage to rise. This, in turn, pulls up the grid of Tube 1 and thus causes a further drop in its plate voltage. This repeated amplification and feedback continues until the grid of Tube 1 is driven positive and the grid of Tube 2 is driven far below cutoff. All this takes place very rapidly, the limiting factor being the rate at which the interelectrode capacitances can be charged and discharged. For many purposes it may be regarded as happening instantaneously.

This action is represented in the equivalent circuits by the reversing of all four switches. Switches 1 and 2 now close, and 3 and 4 open. They remain in this condition until the grid of Tube 2 relaxes to cutoff, at which time the procedure is repeated with the roles of the two tubes reversed. Switches 1 and 2 now open, and 3 and 4 close. When the grid of Tube 1 relaxes to cutoff the cycle is complete.

The analysis of the equivalent circuits has been given previously. With one exception, the multivibrator wave forms are identical with those computed for the equiva-

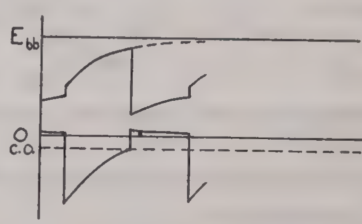

Fig. 5—Plate- and grid-voltage wave forms of one tube of multivibrator in which the plate relaxation is slower than the grid.

lent circuit. In drawing the equivalent circuit it is assumed that the grid voltage is zero at all times while the tube is conducting. As has been pointed out, this is true with the exception of the positive "pip" which occurs when the tube is first driven to conduction. This appears in the plate as an amplified negative peak. Because of the coupling capacitor the peak also appears on the grid of the nonconducting tube where it is superimposed on the exponential rise. If, as is usually the case, the time duration of the peak is small compared with the half-period, this will have little effect on the relaxation time and can be neglected in the calculations. In Fig. 4(c) the actual wave forms are shown as solid lines while the computed wave forms, where different, are shown as dotted lines.

In case the time constant of the circuit involving the nonconducting plate is comparable with that involving the nonconducting grid, the wave forms may be quite

different. The nonconducting plate will not have time to relax to E_{bb}, and the conducting grid will not have time to relax to zero. The resulting wave forms will then be as shown in Fig. 5. An exact calculation of the wave form in this case is impossible. This is because the cutoff voltage on the nonconducting tube is constantly changing, due to the changing plate voltage, and the grid voltage of the nonconducting tube does not follow an exponential curve. Aside from the difficulties in calculating the wave forms in this case, it is usually undesirable to design the multivibrator so that the plate relaxation time is slower than that of the grid, since the resulting wave forms are not as useful as those shown in Fig. 4.

The Biased Multivibrator

A modification of the basic multivibrator is shown in Fig. 6. Instead of returning the grid resistors to the cathode they are returned to a point which is held positive with respect to cathode. This modification is of particular value in high speed circuits and in circuits where good frequency stability is desirable.

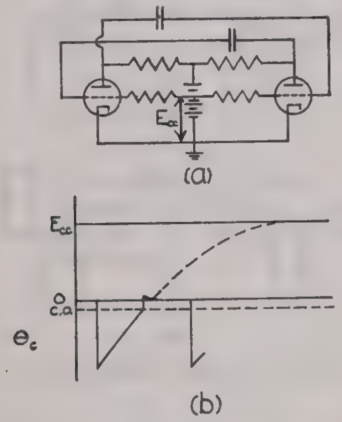

Fig. 6—Biased multivibrator.
(a) Schematic circuit.
(b) Grid-voltage wave forms.

Since the effective grid-to-cathode resistance is small compared with that of the grid resistor, the grid voltage is affected very little by this modification during the part of the cycle when the grid is conducting. The plate wave forms are likewise very little affected. However, during the part of the cycle when the grid is negative, it relaxes toward E_{cc} instead of toward zero, as shown in Fig. 6(b). This has two important effects: it shortens the relaxation time, thus increasing the frequency of the multivibrator; and it increases the rate of change of grid voltage at the time cutoff is reached, thus improving the frequency stability. If in the circuit of Fig. 4 the grid resistors had been returned to a potential of $+240$ volts, E_A would equal $(159+240)=399$ volts and E_B would equal $(159+15)=174$ volts. From (1) the half period would then be $1007 \log_e 399/174=834$ microseconds. The frequency is almost tripled, therefore, by this change. A simple calculation likewise shows that the frequency is stabilized by this modification. Suppose that, due to the substitution of another tube, the cutoff value were changed from -15 to -16 volts. In the unbiased case the new half period would be $1007 \log_e 159/16=2310$ microseconds which is a change of about 2.5 per cent. In the biased case the new frequency would be $1007 \log_e 399/175=830$ microseconds, a change of only about 0.5 per cent.

The dependence of frequency upon the bias value provides a very convenient method of frequency control. By suitable design, the frequency can be varied over as great a range as 10 to 1 by adjustment of the bias.

Special Multivibrators for Producing Square Waves

There are a number of applications in which the plate-voltage wave form of the basic multivibrator is unsuitable because the leading edge of the positive portion of the cycle is an exponential, rather than an instantaneous rise. The plate voltage cannot rise immediately to E_{bb} when the grid is driven below cutoff, because the plate

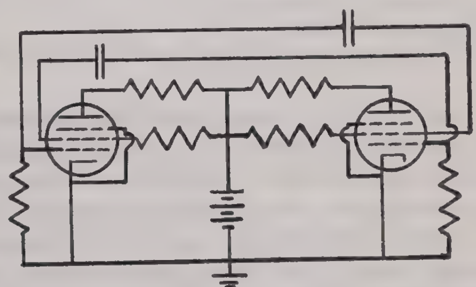

Fig. 7—Pentode multivibrator.

is coupled to the grid of the other tube. Since the grid of the other tube is conducting its effective resistance to cathode is very low, and nearly all the resistance drop due to the charging current of the capacitor appears across the plate load resistor. The plate voltage cannot rise to E_{bb}, therefore, until the capacitor is fully charged. This difficulty can be avoided in two ways: by utilizing pentodes or by adding resistors in series with the grids in the triode circuit.

A pentode multivibrator circuit is shown in Fig. 7. In this circuit use is made of the fact that the cathode, control grid, and screen grid have triode characteristics which are little affected by the plate voltage, provided that it does not fall too low. By connecting these elements in the two tubes as a multivibrator, oscillations will occur just as in the basic multivibrator, and the wave forms can be calculated in the same way if the screen characteristics are known. Since the plate load consists only of a resistor, the plate voltage depends only on the plate current. Thus when the grid is driven below cutoff, the plate voltage rises instantly to E_{bb}, and a very square leading edge results. This circuit is very similar to the ordinary electron-coupled oscillator, in that the load is isolated from the oscillatory circuit.

The leading edge of the plate-voltage wave form of the

triode multivibrator can be made more nearly square by adding resistors in series with the grids. This circuit is shown in Fig. 8(a). The effect of this modification is to reduce the charging current into the coupling capacitor, thus allowing the plate voltage of the nonconducting tube to rise instantly much nearer to E_{bb} when the tube is cut off. The effect is illustrated in Fig. 8(b). Note that

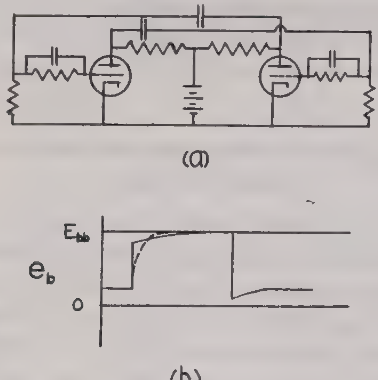

Fig. 8—Square-wave multivibrator.
(a) Schematic circuit.
(b) Plate-voltage wave forms. The dotted curve shows the wave form of the basic multivibrator.

the time constant of the charging circuit is increased, so that the exponential portion of the rise is slower than in the basic multivibrator. The plate wave form can be calculated readily by the method previously described. If, for example, 100-kilocycle resistors are added in series with the grids of the circuit shown in Fig. 4, the plate voltage will rise instantly to 211 volts, instead of to 102 as was the case with the basic multivibrator.

The series grid resistors are usually by-passed with small capacitor (10 to 50 micromicrofarads) as shown in Fig. 8(a). This is done to provide a low-impedance charging path for the interelectrode capacitances. Since the speed with which the electrode voltages can change is limited by the rate at which the voltages on the interelectrode capacitances can be charged and discharged, this circuit detail is necessary to produce sharp leading and trailing edges on the output wave forms.

An incidental effect of this modification is to reduce the amount by which the grid is driven positive, which likewise reduces the size of the negative dip in the plate voltage. This, however, is seldom of any practical importance.

"One-Shot" Multivibrators

There are a number of important applications in which it is desired that the multivibrator remain quiescent until its action is initiated by a voltage pulse or "trigger." The circuit then goes through one cycle of operation, at the end of which it reverts to the original quiescent state where it remains until triggered again. Such a circuit is called a one-shot multivibrator.

Any of the circuits previously discussed can be modified to make a one-shot multivibrator by biasing one of the grids below cutoff. In the quiescent condition this tube remains cut off and the other one conducting. To initiate the cycle, the grid of the nonconducting tube must be brought above cutoff. This can be accomplished by means of a positive trigger applied directly to the grid of the nonconducting tube, or a negative trigger to the grid of the conducting tube. In the latter case, the trigger is amplified and its polarity inverted. It is then transmitted by means of the coupling capacitor to the grid of the nonconducting tube.

Typical one-shot multivibrators are shown in Fig. 9. The circuit of Fig. 9(a) is the basic multivibrator modified by placing sufficient negative bias on the grid of tube 1 to hold it below cutoff. After triggering, the wave forms of this circuit are very similar to those of the basic circuit with a positive pulse appearing on the plate of tube 2, and a negative pulse of the same duration on the plate of tube 1. The duration of these pulses is determined primarily by the time constant of the circuit coupling the plate of tube 1 to the grid of tube 2.

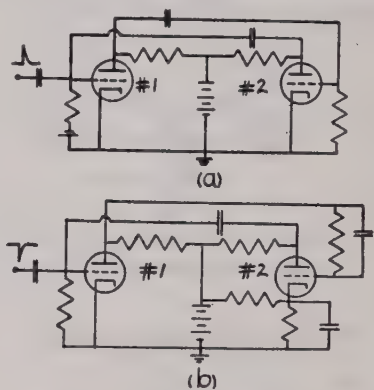

Fig. 9—One-shot multivibrator.

Another one-shot circuit is shown in Fig. 9(b). This differs from the other circuits discussed in this paper in that the coupling between the plate of tube 1 and the grid of tube 2 are through a resistor rather than a capacitor. The small capacitor by-passing the resistor is not essential, but aids in charging and discharging the input capacitance of tube 2, thus improving the rapidity of operation of the circuit. Sufficient positive bias is placed on the cathode of tube 2 to hold it cut off, even though the grid is held positive with respect to ground by an amount equal to the plate voltage of tube 1. When the circuit is triggered by bringing the grid of tube 2 above cutoff, this grid is driven slightly positive and the other grid is driven far below cutoff. The circuit remains in this condition until the grid of tube 1 relaxes to cutoff, at which time the circuit immediately reverts to its quiescent condition. Thus a positive pulse appears on the plate of tube 1 and a negative pulse on the plate of tube 2. The duration of the pulse is controlled by the time constant of the coupling network between the grid of tube 1 and the plate of tube 2. This circuit is particularly useful, since the leading edge of the positive pulse appearing on the plate of the left-hand tube

consists of an instantaneous jump to the final value instead of an exponential rise.

The coupling capacitor which couples the triggering circuit to the multivibrator should be made as small as possible in most cases. This will insure a short trigger pulse and will minimize the loading of the multivibrator by the triggering circuit.

High-Frequency Characteristics of Multivibrators

In the simplified analysis given previously, the interelectrode and wiring capacitances were neglected, and under these conditions instantaneous voltage changes occur on both the plate and grid wave forms. In practice these capacitances are present, of course, and as with any capacitance it is impossible for the voltage across them to change instantly. Although instantaneous changes are impossible, in many recent applications of the multivibrator it is of great importance that they be very rapid, and the problem of accomplishing this is often a serious one in multivibrator design. As in the case of a video amplifier, the rapidity with which the electrode voltages can be changed is proportional to the upper frequency limit of the circuit, and the same design factors are involved. Although a rigorous determination of the time of rise and fall of voltage is practically impossible because of the complexity of the circuit and the nonlinear characteristics of the tubes, a few important generalizations can be made.

At the point in the cycle when the plate voltage on one of the tubes suddenly drops from E_{bb}, the voltage must change across the output capacitance of the tube, the input capacitance of the other tube, and the wiring capacitance. The resistance effectively in series with these capacitances is the load resistor in parallel with the dynamic plate resistance of the tube. It is apparent, therefore, that for greatest speed of operation it is necessary in order that all capacitances, the load resistor, and the plate resistance be as small as possible. For this reason low-μ triodes which have a low plate resistance are preferred to high-μ tubes. In certain applications which demand an extremely rapid voltage change, power-amplifier tubes, especially beam-power tubes, are sometimes used. Since these tubes can be operated with a small load resistor their high-frequency characteristics are excellent. The exact calculation of the time required for the voltage to drop is complicated by the fact that the grid voltage is not driven instantly from cutoff to its positive value. Also, the effective input capacitance of the other tube cannot readily be calculated; (the ordinary Miller-effect equation cannot be used because the tube is not operating as a linear amplifier). Experimental results show, however, that this time is of the order of one fourth the reciprocal of the upper-half power frequency of one of the tubes operated as an ordinary linear amplifier.

The rounding of the leading edge of the positive portion of the plate wave form in the basic multivibrator is due primarily to the charging of the coupling capacitor, since this is normally much larger than the interelectrode capacitances. In the case of the special multivibrator circuits previously discussed, which were designed to have a square leading edge, the rise time will be determined by the same factors that determined the time of fall. In this case, however, the plate resistance is no longer in parallel with the load resistor, since the tube is cut off at this time. For this reason the time of rise is usually slower, especially with triodes, where the plate resistance is often lower than the load resistor.

A very square wave form can be obtained by taking the output across a small (50 to 1000 ohms) resistor inserted in the cathode circuit of one of the tubes. The output impedance of this circuit is very low, which makes the high-frequency characteristics excellent. This arrangement is particularly suitable for feeding a low-impedance load such as a transmission line.

The Reactance Theorem for a Resonator*

W. R. MacLEAN†, associate, i.r.e.

Summary—**The Foster reactance theorem which states that in any loss-free network, $dX/d\omega$ is positive, is here proved for any loss-free resonator. However, to establish the existence of an input impedance, the author feeds the resonator with a coaxial (or other suitable) transmission line. The proof is based upon an extension of Helmholtz's theorem of adiabatic invariants. The variation of frequency is attained by a slow (adiabatic) movement of a short-circuiting plug in the transmission line while the cavity is oscillating.**

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Introduction

Foster's reaction theorem[1] states that the driving-point reactance of any nondissipative network is an odd rational function of the frequency with an always positive slope. The usual proof is based on network theory and limits its validity to configurations of a finite number of degrees of freedom. The principle can and has been extended to certain systems of distributed parameters such as transmission

[1] R. M. Foster, "A reactance theorem," *Bell Sys. Tech. Jour.*, vol. 3, pp. 259–268; April, 1924.

lines.[2] Such extensions, however, are made to systems for which the impedance function can be determined explicitly. They have then always been found to obey Foster's principle, if one merely allows the impedance function to become meromorphic instead of just rational. It has long been assumed that the theorem was valid for any nondissipative system whatever, but it has not been proved, so far as the author is aware, for the general case of an unrestricted electromagnetic configuration. It is the purpose of this paper to extend the theorem to a configuration which is specialized only insofar as needed to establish the existence of a driving-point impedance.

To have an impedance in the first place, it is necessary to have a definable voltage and current whose ratio can be taken. In the completely general case, since no scalar-potential function exists, there is no such thing as voltage and hence no impedance. Therefore, the input to the system must be so arranged that a voltage exists at some point, or the theorem has no meaning. Also, if the system is to have no resistance component of input impedance it must be not only nondissipative but also nonradiative. Hence, it must be considered to be made of perfect conductors and to be completely surrounded with a perfectly conducting shield.

Suppose, then, that one has such an enclosure whose internal configuration is any whatever, but which is fed through an attached concentric transmission line, or simply a grounded, shielded, and uniform line. If the frequency is below that required for the propagation of higher modes within the line, and if the line is of sufficient length and fed in any manner whatever at the far end, there will exist at any point which is some diameter distant from the resonator and also from the far end, a field pattern which is purely that of the principal mode. For this mode, the curl of the electric field lies in the transverse planes, and hence in these planes a scalar potential exists. This defines a difference of potential between the outer and inner conductor which is the ordinary "voltage on the line."

A value of current can be defined as the net flow through the center conductor toward the resonator that crosses the same transverse plane used for the voltage. The ratio of these two gives the input impedance to the resonator at a fixed point on the transmission line which needs be a few diameters distant from the resonator. This definition is valid from direct current up to frequencies whose wave lengths become comparable with the diameter of the transmission line, and coincides with the usual concept of impedance.

Since with a given apparatus there is a limit to the region of frequency in which the impedance is defined, we cannot hope to be able to evaluate the function by a knowledge of its poles and roots. But it is possible to show that, within the range of definition, the reactance function is odd, and has a positive slope.

[2] Dah-You Maa, "A general reactance theorem for electrical, mechanical, and acoustical systems," Proc. I.R.E., vol. 31, pp. 365–371; July, 1943.

I. The Reactance Function is Odd

Having decided on a certain concentric feeder, and having picked a transverse plane O through this line at which the impedance is to be determined, one considers the cavity bounded by the perfectly conducting metal surfaces and by an annular ring cut out of O by the transmission line. Within this region, the theorem

$$-\int_S \overline{N}\cdot dS = j2\omega(T-U) \tag{1}$$

can be applied.[3]

In (1), $\overline{N}$ is the complex poynting vector, T is the total (time-averaged) magnetic energy, and U is the total (time-averaged) electric energy. The integral is taken over the bounding surface with outwardly directed normal. Due to the perfectly conducting metal, the integral vanishes except over the annular ring. If ω is less than the value ω^0 at which the impedance definition breaks down, the integral can be evaluated over the ring since the mode is known to be the principal one. A little computation leads to

$$\overline{V}\overline{I} = j2\omega(T-U) \tag{2}$$

where $\overline{V}$ and $\overline{I}$ are the complex voltage and current at O. Instead we could write

$$Z = j2\omega(T-U)/I^2 \tag{3}$$

or

$$X = 2\omega(T-U)/I^2 \tag{4}$$

where X is the input reactance.

Substituting $-\omega$ for ω will produce no change in the energies (since there is no physical change involved). Hence

$$X(-\omega) = -X(\omega) \tag{5}$$

and we see that the function is odd.

II. The Slope is Always Positive

To demonstrate this property of the reactance function, we first imagine the concentric feeder extended indefinitely behind the plane O and finally closed with a frictionless plug at a distance ζ from O. This is shown schematically in Fig. 1. We then pick a starting frequency, ν, as low as we please and determine the reactance X, at O of the resonator for this frequency. ζ is then adjusted so that

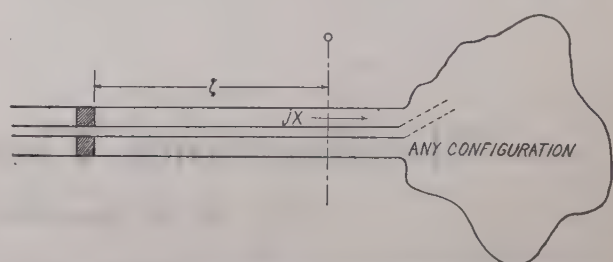

Fig. 1—A general resonator with concentric feeder.

$$X = -R_0 \tan(2\pi\nu\zeta/c) \tag{6}$$

where R_0 is the characteristic resistance of the concentric line. As a result, there is a conjugate match at O at this frequency. Consequently the system, resonator,

[3] J. A. Stratton, "Electromagnetic Theory," McGraw-Hill Book Co., Inc., New York, N. Y., 1941, p. 137.

and line out to the plug, has a natural mode at this frequency, and if started in oscillation would continue indefinitely since there is no dissipation.

We now start it oscillating at this lowest frequency, and then move the plug with infinite uniform slowness toward the resonator. This movement will take place against the radiation pressure. Hence it will increase the energy of the mode; but it will also change the frequency. The frequency will always be such that a conjugate match exists at every point on the line where an impedance exists. By this principle, the impedance of the resonator at O will be given by (6) even when ν, X, and ζ have been modified from their starting values.

As a result of the infinitely slow deformation, ν will be a function of ζ and vice versa, and X will be a function of either ν or ζ. Hence

$$dX/d\nu = -R_0 \sec^2(2\pi\nu\zeta/c)(2\pi/c)(\nu d\zeta/d\nu + \zeta). \quad (7)$$

To prove the stated proposition, we must show that the right-hand side of (7) is positive. All the quantities are intrinsically positive except the minus sign and the final bracket. Information concerning the sign of this bracket can be obtained by relating the change in frequency to the change in energy of the mode.

Such a relation is given by the fact that the action of a resonator is an adiabatic invariant. By this is meant that, if W is the energy and τ the period, the product τW cannot be changed by a deformation (slow compared to the period). In symbols[4]

$$\delta(\tau W) = 0. \quad (8)$$

Another formulation would be

[4] J. H. Jeans, "Dynamical Theory of Gases," Cambridge Press, London, England, 1925, pp. 410–417. This theorem is proved for a machine of a finite number of degrees of freedom. A proof for an electromagnetic resonator is given by the author in *Quart. Appl. Math.*, vol. 2, pp. 329–335; January, 1945.

$$\delta W/W = \delta\nu/\nu \quad (8a)$$

and since one is putting in energy in moving the plug towards the resonator, the frequency is thereby continually increased. $\nu(\zeta)$ is hence monotonic and $\zeta(\nu)$ single-valued.

Now, however, the radiation pressure gives us information concerning the change in energy and leads to the desired result. First, it can be shown by a variety of means that the electromagnetic force F on the plug is equal to the linear density of time-averaged energy w along the line

$$F = w. \quad (9)$$

Hence

$$-dW/d\zeta = w \quad (10)$$

which with (8a) leads to

$$(1/\nu)(d\nu/d\zeta) = (1/W)(dW/d\zeta) = -w/W \quad (11)$$

or

$$\nu(d\zeta/d\nu) = -W/w. \quad (12)$$

Substituting this result in (7) one has

$$dX/d\nu = R_0 \sec^2(2\pi\nu\zeta/c)(2\pi/c)((W - w\zeta)/w). \quad (13)$$

$w\zeta$ is only the energy contained in part of the transmission line, whereas W is the entire energy of the oscillating cavity. Hence $dX/d\nu$ is always positive while the plug moves from its original position up to the plane O.

When the plug has reached O, the frequency has risen to a value say ν_1. We then stop the oscillation and move the plug back some large whole number of wave lengths of this frequency ν_1. In this new position, the system has *a* mode of this same frequency since the conjugate match principle at O is maintained. We create this mode and again push the plug toward the resonator. Hence it is seen that the slope of the reactance curve is always positive up to those frequencies for which the impedance is no longer defined.

"N"-Phase Resistance-Capacitance Oscillators*

R. M. BARRETT†, ASSOCIATE, I.R.E.

Summary—This paper describes the design of a series of resistance-capacitance tuned oscillators of the polyphase type. A single-mesh phase-shift network is used for coupling the N tubes of the oscillator which are arranged in a feedback ring. Limiting the discussion to oscillators of odd phases, the author has developed design formulas and has analyzed typical circuits. Experimental results are shown to check closely those predicted by theory.

I. Introduction

A VACUUM-TUBE oscillator is, essentially, a converter that changes direct-current plate power into alternating-current energy. This converter consists of a vacuum-tube amplifier and a coupling network, so arranged that an exciting voltage of the proper magnitude and phase to produce the amplified output is obtained from this output.

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The feeding of a signal back to the grid circuit in phase with the input voltage so that it aids oscillations is called positive feedback. The feeding back of a signal out of phase with the input signal in such a way as to hinder and reduce the oscillations is called negative feedback. Since the tube normally produces a phase shift of 180 degrees, the feedback network must provide another shift of approximately 180 degrees to make the voltage being fed back in phase with the initial grid voltage. The coupling network must also provide a frequency-selective characteristic so as to maintain single-frequency operation.

In common with the recently popularized resistance-capacitance oscillators, the N-phase oscillators described in this paper use a resistance-capacitance phase-shift

network to provide positive feedback at the selected frequency. This coupling network is so designed that it not only causes positive feedback, with its accompanying amplification at the selected frequency, but it also provides negative feedback for the harmonic frequencies of the oscillator, thus assuring a distortion-free type of oscillation.

This paper is mainly concerned with N-phase oscillators of the resistance-capacitance phase-shift type. The author has found that, although inductive circuits can be used, they are, on the whole, unsatisfactory and usually are of a more complex nature. The oscillators described herein have the advantages of simplicity, stability, and unusually pure wave form. The design follows closely the single-tube phase-shift oscillator recently described in the literature.[1] The phase-shift network has been divided into N symmetrical sections coupled by single-stage amplifiers. This necessitates a

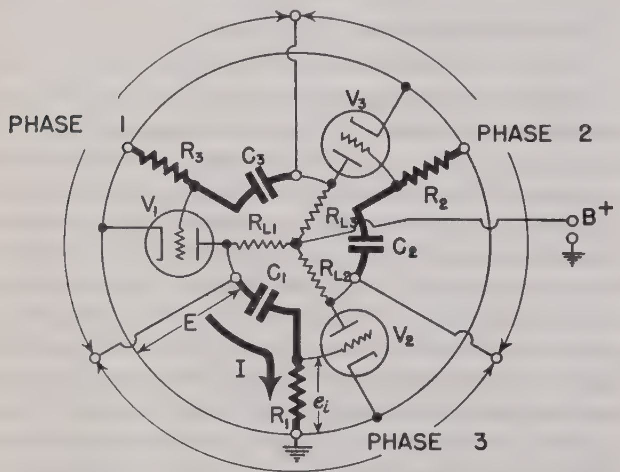


Fig. 1—The three-phase oscillator.

total phase shift of $\pi(n+1)$, for n odd, the phase shift $n\pi$ being taken care of by the N coupling amplifiers, leaving a 180-degree phase shift to be accomplished by the N interstage coupling networks. It is evident that as the number of phases increases, the phase shift per stage decreases, and, in all cases, the simple resistance-capacitance coupling network of the resistance-coupled amplifier produces sufficient phase shift for oscillation.

The following analysis is limited to the discussion of amplifiers of odd phases as the resistance-capacitance-type phase-shift network discussed in this paper is unsuitable for use with sine-wave oscillators where the number of phases generated is even.

II. Basic Circuit Analysis[2]

In order to produce self-sustaining N-phase oscillations in a multistage amplifier, three conditions must be satisfied. First, the stages must have identical characteristics; second, the output of the amplifier must be in phase with its input; and third, the over-all gain of the network must be equal to or greater than unity. That is, if

A_k = amplification parameter of an amplifier stage

B_k = fraction of the output voltage of an amplifier stage introduced into the input of the next stage

then,

$$A_1B_1 \times A_2B_2 \times A_3B_3 \times \cdots \times A_nB_n = \prod_{k=1}^{k=n} A_kB_k \geqq 1. \quad (1)$$

Thus, if

$$A_1 \times A_2 \times A_3 \times \cdots \times A_n = |A_1| \underline{/\theta_1} \times |A_2| \underline{/\theta_2} \times \cdots \times |A_n| \underline{/\theta_n} = \prod_{k=1}^{k=n} |A_k| \underline{/\theta_k} \quad (2)$$

$$B_1 \times B_2 \times B_3 \times \cdots \times B_n = |B_1| \underline{/\phi_1} \times |B_2| \underline{/\phi_2} \times \cdots \times |B_n| \underline{/\phi_n} = \prod_{k=1}^{k=n} |B_k| \underline{/\phi_k} \quad (3)$$

then,

$$|A_1||B_1| \times |A_2||B_2| \times \cdots \times |A_n||B_n| = \prod_{k=1}^{k=n} |A_k||B_k| \geqq 1 \quad (4)$$

$$(\theta_1+\phi_1)+(\theta_2+\phi_2)+\cdots+(\theta_n+\phi_n) = \sum_{k=1}^{k=n} (\theta_k+\phi_k)$$

$$= \text{zero or any integral multiple of } 2\pi. \quad (5)$$

From these equations it can be seen that an N-phase oscillator must consist of an amplifier capable of developing a voltage amplification of $1/\prod_{k=1}^{k=n}|B_k|$ and a phase-shifting network that will satisfy the phase equation (5).

The requirements for individual stages of an N-phase oscillator are slightly different. The amplification of the stage must still be greater than, or equal to unity, but the stage output will have a definite phase shift with relation to its input, depending upon the number of phases being produced by the oscillator.

In this case,

$$A_kB_k \geqq 1\underline{/\pi(n+1)/n}. \quad (6)$$

Thus, if

$$A_k = |A_k| \underline{/\theta_k} \quad (7)$$

$$B_k = |B_k| \underline{/\phi_k} \quad (8)$$

then

$$|A_k||B_k| \geqq 1 \quad (9)$$

$$\theta_k+\phi_k = [\pi(n+1)/n] \text{ (when } n \text{ is an odd integer).} \quad (10)$$

In the usual case

$$\theta = \pi \quad (11)$$

$$\phi = [(\pi(n+1)/n)-\pi] = \pi/n \text{ (when } n \text{ is an odd integer).} \quad (12)$$

The circuit shown in Fig. 1 is that of a three-phase, resistance-capacitance coupled amplifier and its phase-shifting networks. To a close approximation we can assume that the amplifier stages have a phase shift of 180 degrees. In order to satisfy (10) and (12), the interstage coupling networks must be able to produce a phase shift of π/n or in the case of a three-phase oscillator [+60 degrees]. As will be seen, the ordinary resistance-capacitance coupling network is capable of accomplishing this for the N-phase case, although more complex networks must be used for single-phase oscillators.

The voltage amplification required by each stage depends critically on the type of phase-shift network used, being equal, numerically, to the attenuation of the coupling circuit at the frequency which produces a phase shift that is equal to π/n.

[1] E. L. Ginzton and L. M. Hollingsworth, "Phase-shift oscillators," Proc. I.R.E., vol. 29, pp. 43–49; February, 1941.

[2] The analyses of this paper adapt those of Ginzton and Hollingsworth to the N-phase case.

The second and higher-order harmonics occur at frequencies where the reactance of the coupling capacitor C_c is low and the phase shift through the coupling network approaches zero. Thus, the total phase shift of the three stages for harmonic frequencies will be approximately $[n\pi]$ (540 degrees for the three-phase case). This means that the harmonics will introduce a voltage almost 180 degrees out of phase into the amplifier input, reducing the output, thus effectively producing a negative-feedback amplifier with 100 per cent negative feedback and a zero output, at these frequencies. This tends to maintain a harmonic-free, pure sine-wave type of oscillation. This is especially true when the gain of the circuit is adjusted to a value that barely allows oscillations to be maintained. As a result of this linear operation of the amplifier, the generated harmonics are very low.

As in any multistage negative-feedback amplifier, care must be taken in the amplifier design to prevent unwanted oscillations at the edges of the pass band of the amplifier. In such amplifiers, the relative phase shift approaches 180 degrees near both the upper and lower edges of the pass band. To prevent oscillation at these points, it is necessary to insure that, at the extreme band limits, where the phase shift is high, the amplification has fallen off sufficiently so that the feedback factor of the amplifier is less than unity.

In the case of the N-phase oscillator, the phase-shift characteristics at the lower edge of the pass band are used to produce oscillations whose frequency is determined by the lower pass-band characteristics. Thus, it is necessary only to suppress the spurious oscillations at the extremely high frequencies.[3] Oscillations at the upper edge of the pass band are best avoided by controlling the rate of cutoff; for example, by connecting a large shunt capacitor across one stage so as to reduce its gain to such an extent that the feedback factor will be less than unity at the point where the total phase shift of the N stages is 180 degrees.

III. Theoretical Analysis of the Three-Phase Case

Fig. 2(a) illustrates a single stage of the three-phase oscillator of Fig. 1. This can be represented by the equivalent circuit of Fig. 2(b), which may be further simplified by the use of Thevenin's theorem, to that of Fig. 2(c). The frequency of oscillation may be computed by finding the total amplification of the circuit, $|A_k||B_k|$, and finding the frequency at which the phase shift of the coupling network, is equal to π/n.

From Fig. 2(c) the following set of equations may be written for the stage network.

[3] In some cases there will be more than one condition at which the phase shift at the lower edge of the pass band will total 180 degrees. For example, if $n=7$ then $\phi=25\text{-}5/7$ or $\phi=77\text{-}1/7$. If this condition causes spurious oscillations, it may be necessary to control the rate of cutoff, at the lower edge of the pass band, in such a way that the feedback factor will be less than unity for the larger phase shift.

In the normal oscillator this is not necessary, as the gain has dropped off to such an extent, at this point, that oscillations cannot occur.

$$I(R_1 + R - jXc) = E \qquad (13)$$

$$e_0/E = \alpha + j\beta = \sqrt{\alpha^2+\beta^2}\,\underline{/\tan^{-1}\beta/\alpha} \qquad (14)$$

$$\tan^{-1}\beta/\alpha = \pi/n. \qquad (15)$$

Solving for I, $\quad I = E/R_1 + R - jXc.$

Since $e_0 = IR$,

$$e_0/E = R/(R_1+R-jXc) = (R(R+R_1)/(R+R_1)^2+Xc^2) + (jRXc/(R+R_1)^2+Xc^2) = \alpha + j\beta.$$

Or, since $\quad \tan^{-1}\beta/\alpha = \pi/n = 60$ degrees,

$$\beta/\alpha = \sqrt{3} = RXc/R(R+R_1) = (1/2\pi fC/(R+R_1)).$$

Therefore, $\quad f = 1/2\pi C\sqrt{3}(R+R_1). \qquad (16)$

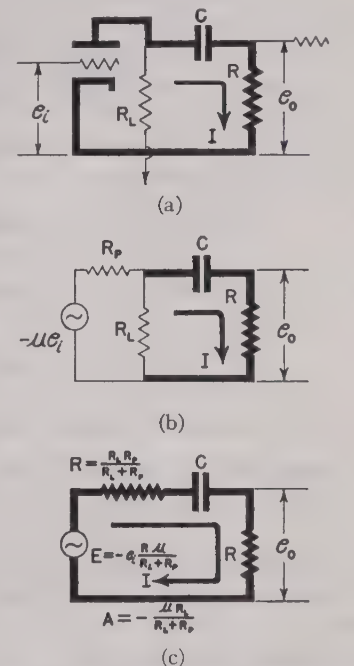


Fig. 2—Single stage of fundamental phase-shift oscillator.

The minimum gain necessary for oscillation may be determined from (14), since the scalar part of this equation determines the attenuation of the coupling network. But $E = Ae_i$, in order to produce oscillations e_i must equal e_0, therefore

$$e_0 = e_i \qquad E = Ae_i \quad \text{or} \quad e_0/E = 1/A.$$

$E/e_0 = [(R+R_1) - jX_c]/R = A$ (from (13))

$$A = |A|\,\underline{/\phi} = \sqrt{[R+R_1/R]^2 + [1/\omega RC]^2}\cdot\underline{/\tan^{-1} Xc/(R+R_1)}$$

$$= \sqrt{[1+(R_1/R)]^2 + [\sqrt{3}(R+R_1)/\sqrt{3}(R+R_1)\times 1/\omega RC]^2}\,\underline{/\tan^{-1}\sqrt{3}/\sqrt{3}[1/\omega C(R+R_1)]}$$

$$A = |A|\,\underline{/\phi} = \sqrt{[1+(R_1/R)]^2 + [3(f_0/f)^2\{1+(R_1/R)\}^2]}\cdot\underline{/\tan^{-1}[\sqrt{3}(f_0/f)]}.$$

At resonance $f = f_0$ this reduces to

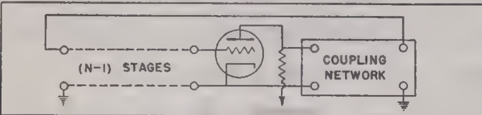
$$|A| = 2[1 + (R_1/R)]. \qquad (17)$$

Fig. 3 presents the characteristics of the coupling networks for several different N-phase oscillators. It will be noted that, with the exception of the single-phase case, all of the oscillators use the simple coupling network of the resistance-coupled amplifier.

IV. Frequency Stability

Unfortunately the frequency of oscillation is determined not only by the phase-shifting network but also by the value of R_1 which varies with operating conditions of the oscillator.

The greatest variation of R_1 is caused by the change in plate resistance R_p of the tube, due to plate-voltage variations. It is, therefore, instructive to compute the frequency stability with reference to plate-resistance variations.



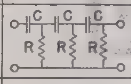
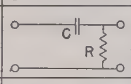
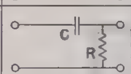
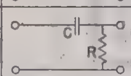
NUMBER OF PHASES	COUPLING NETWORK	REQUIRED GAIN	NETWORK PHASE SHIFT	FREQUENCY OF OSCILLATION
N = 1		29	180°	$F=\frac{1}{2\pi\sqrt{6}RC}$
N = 3		$2(1+\frac{R_1}{R})$	60°	$F=\frac{1}{2\pi\sqrt{3}C(R_1+R)}$
N = 5		$1.24(1+\frac{R_1}{R})$	36°	$F=\frac{1}{1.45\pi C(R_1+R)}$
N = 7		$1.11(1+\frac{R_1}{R})$	$25\frac{5}{7}$°	$F=\frac{1}{0.963\pi C(R_1+R)}$

Fig. 3—Characteristics of coupling networks.

Let df be a small change in the frequency f due to the change in the resistance dR_1 resulting from a plate-voltage variation.

Frequency stability is defined as

$$\frac{\text{Incremental change in oscillator frequency}}{\text{Frequency of the oscillator}} = -K_1'\frac{\text{Incremental change in }(R_1+R)}{(R_1+R)}$$

or $\Delta f/f = -K_1'(\Delta(R_1+R)/(R_1+R))$.

$df/f = -K_1'(dR_1/(R_1+R)) = -K_1(dR_1/R_1)$ where K_1 is the coefficient of stability. By a change in variables, this equation becomes

$$df/f = -K_2(dR_p/R_p). \tag{18}$$

The frequency stability of a three-phase oscillator is computed below.

$$f = 1/2\pi C\sqrt{3}(R+R_1) \quad R_1 = (R_LR_p/R_L+R_p).$$

Differentiating with respect to R_p

$$df = [1/2\pi C\sqrt{3}]^{(-1)}(R_1+R)^{-2}dR_1$$

$$= (-1/2\pi C\sqrt{3})\times(R_L{}^2dR_p/(R_1+R)^2(1+R_L/R_p)^2R_p{}^2,$$

$$df/f = -R_L{}^2/[R_L+R_p][R_L+R(1+R_L/R_p)]\times(dR_p/R_p).$$

Therefore

$$K_2 = +R_L{}^2/[R_L+R(1+R_L/R_p)][R_L+R_p]. \tag{19}$$

For example, a typical design has the following set of constants.

$R_L = 10{,}000$ ohms $\quad R = 1{,}000{,}000$ ohms
$R_p = 1{,}000{,}000$ ohms $\quad f = 1000$ cycles per second

Substituting these values in (19), one finds that $K_2 = +9.7\times 10^{-5}$. Thus a 10 per cent change in plate resistance of the amplifier tubes would result in a frequency change of 9.7×10^{-4} per cent or 0.0097 cycles per second. The frequency stability of this three-phase oscillator compares favorably with that of a regular single-phase phase-shift oscillator. Using the same constants, a single-phase oscillator would have a frequency shift of 0.0033 cycle per second, one third the shift of the three-phase case.

V. Experimental Results

Single-phase oscillators of the phase-shift type are often sluggish in starting, due to the high gain needed to produce sufficient feedback for oscillation. This is especially true in variable-frequency oscillators where the attenuation of the phase-shifting network varies with frequency. In the polyphase case, however, the network attenuation is low, eliminating the need for high-gain tubes and thus insuring quick, positive starting oscillators.

Experience has shown that best sine-wave production is obtained where oscillations are barely sustained. Therefore, where purity of wave form is important, automatic amplitude control is indicated. Such arrangements are of especial value in variable oscillators covering an extended frequency range. When properly adjusted, this type of phase-shift oscillator generates high-precision sine waves with less than 0.1 per cent harmonic distortion.

One of the principal difficulties encountered in adapting the circuit of Fig. 1 to practical operation is in the application of variable-amplification control to the circuit. The most obvious means of using sharp cutoff tubes, biased near cutoff, to obtain variable-amplification-factor control of the amplitude of oscillations, is unsatisfactory as it generates unwanted harmonics and gives a very low output voltage. Although this type of control could be improved by using variable-*mu* tubes rather than sharp cutoff types, working as variable *mu* by excessive bias, some variable-amplification-control arrangement not involving variational tube characteristics is desirable. With this type of control, it would be possible to operate on the linear portion of the tube characteristic and obtain larger outputs without the accompanying distortion.

The method of amplitude control finally selected is patterned after that of Meacham,[4] in that a thermal element (thermistor) is used as an amplitude control. This gives a type of amplitude limitation which allows the oscillator to operate on the linear portion of its characteristic, thus allowing a considerable amount of undistorted output to be obtained. The thermistor-controlled bridge, in contrast with the usual variable-amplification-control circuits, has several interesting and important properties. It has an infinite cutoff, at balance, whereas ordinary variable-amplification-control.

[4] L. A. Meacham, "The bridge-stabilized oscillator," Proc. I.R.E., vol. 26, pp. 1278–1294; October, 1938.

circuits have restricted ranges. Also, since the thermistor resistance cannot change materially over the time of one cycle of oscillation frequency (due to thermal inertia), the thermistor-controlled bridge introduces no distortion, or phase shift, with its consequent alterations of the frequency of oscillation as regulation takes place.

Fig. 4 shows the adaption of the negative-feedback thermistor bridge to a three-phase oscillator. It will be noted that the fundamental circuit has been modified by the addition of a cathode follower to each amplifier stage. These cathode followers supply the feedback voltage for the thermistor bridge and also allow push-pull output to be obtained from the individual stages.

For the oscillator to be satisfactory, this two-stage resistance-coupled amplifier must have a phase shift that is constant and independent of changes in supply voltages, etc. In addition, the means by which the amplitude of oscillation is controlled, so that the tubes will operate as class A amplifiers, must not depend on, or affect, the tube characteristics.

Constant amplifier phase shift is necessary in order to insure a stable frequency. This is because the phase shift of the interstage transfer impedances of the resistance-capacitance networks vary slowly with frequency. Hence, small changes in amplifier phase shift, as could be brought about by a variation in supply voltage, require a large change in oscillator frequency to produce a compensating phase shift in the resistance-capacitance system.

A stable phase characteristic, such as is obtained in this circuit by means of the negative-feedback thermis-

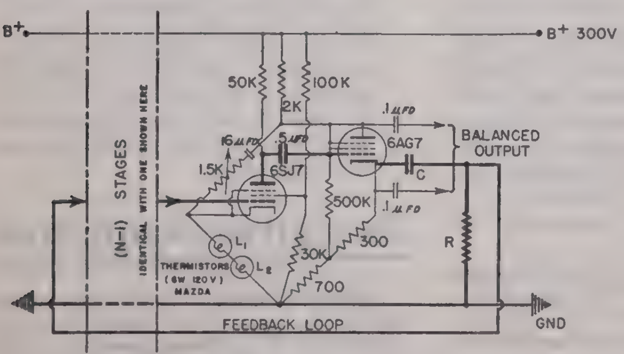


Fig. 4—One stage of the experimental oscillator.

tor bridge, can be obtained readily in the amplifier by using a large amount of negative feedback. This large amount of negative-voltage feedback, plus the use of the second tube as a cathode follower, reduces and stabilizes the output impedance of the tubes to such an extent that the frequency of oscillation is practically independent of changes in the supply voltages or the characteristics of the amplifier tubes. The output impedance of the cathode follower is so low that in formula for frequency (16), it is possible to neglect the term R_1.

Amplitude control (variable-amplification-control action) is obtained by the nonlinear action of the negative-feedback thermistor bridge which prevents oscillations from building up to such a large amplitude that distortion occurs. The cathode bias of V_1 is supplied by the

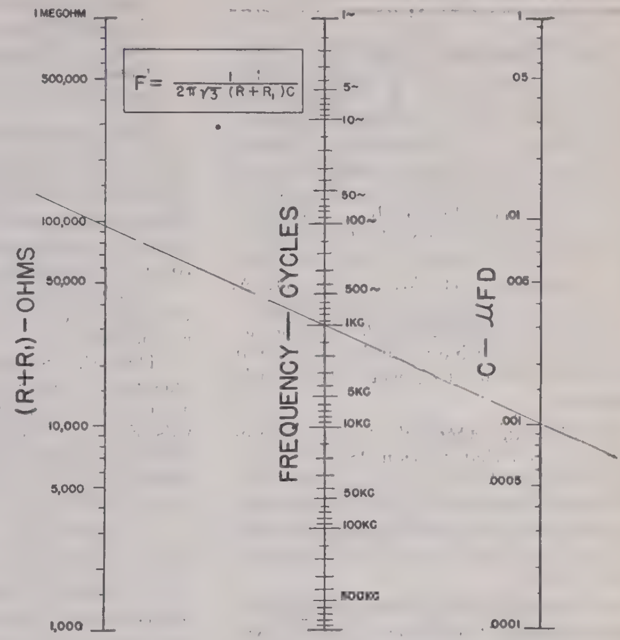


Fig. 5—Nomograph for the design of three-phase oscillators.

voltage across the thermistor, the resistance of which varies rapidly with current at the temperature at which they operate in the circuit. Thus, an increase in oscillation amplitude increases the thermistor resistance. This makes the negative feedback larger and decreases the gain of the amplifier, reducing its tendency to oscillate. Similarly, as the oscillations decrease in amplitude, the current through the thermistor is reduced, lowering its resistance and thus reducing the negative feedback and increasing the oscillator's tendency to oscillate. The resultant effect is that a constant amplitude of oscillation is maintained with no tendency to distort the wave shape. The absolute amplitude of oscillation can be varied by adjusting the resistance arm R_3 of the feedback bridge.

Although the circuits discussed in this article are directly applicable only to the generation of oscillations of odd phases, that does not preclude the possibility of using them as components of networks developing even-phase voltages. For example, with the addition of a phase inverter to each stage of a three-phase oscillator, a six-phase output can be obtained (see Fig. 4). The common methods of phase changing such as the Scott-T connection may also be used.

The nomograph of Fig. 5 is very convenient for use during the preliminary design of three-phase oscillators. This nomograph is accurate enough for ordinary work where the greatest errors arise from the relatively large tolerances in commercial components.

Institute News and Radio Notes

Board of Directors

June 6 Meeting: At the June 6, 1945, meeting of the Board of Directors, the following were present: W. L. Everitt, president; G. W. Bailey, executive secretary; S. L. Bailey, W. L. Barrow, E. F. Carter, L. M. Clement, W. H. Crew, assistant secretary; Alfred N. Goldsmith, editor; R. F. Guy, R. A. Hackbusch, R. A. Heising, treasurer; Keith Henney, L C. F. Horle, F. B. Llewellyn, Haraden Pratt, secretary; W. O. Swinyard, H. M. Turner, H. A. Wheeler, L. P. Wheeler, and W. C. White.

Executive Committee Actions: The actions of the Executive Committee, taken at its June 6, 1945, meeting, were unanimously approved.

Membership Approval: It was unanimously agreed that Section 25 of the Bylaws be altered so as to empower the Executive Committee to give *final* approval to applications for transfers and admissions to any grade of membership, with the exception of Fellow.

Constitutional Changes Regarding Membership Period: Unanimous approval was given to the recommendation that the Constitution and Laws Committee be instructed to prepare changes in the Constitution which will permit the dating of a member's period of membership, when approved, back to the first of the month after the receipt of his application; which will cause the member's annual dues period to run correspondingly; and will cause his receipt of the publications of the Institute to run concurrently with his membership period.

Constitutional Voting on Suggested Changes: Approval was given to the recommendation that the Constitution and Laws Committee, if possible, arrange for the submission of the constitutional amendments proposed in Minute 160 to the membership at a time to permit the voting thereon to be received and recorded before the end of 1945.

Canadian Council: The recommendation to transmit to the Canadian Council a fund of a specific amount deemed suitable to cover operating expenses for 1945 was unanimously approved.

Committees and Appointments

Constitution and Laws: The following, proposed constitutional amendments were submitted:

(a) "*Article II, Section 1b:* Senior Members, who shall be entitled to all rights and privileges of the Institute."

(b) "*Article II, Section 1d:* Associates, who shall be entitled to all rights and privileges of the Institute except the right to hold any office, including those of the Sections, the Chairmanship of any Standing Committee, and the right to vote. However, Associates of record on March 31, 1939, shall have the right to vote so long as a continuous membership since that date is maintained. Furthermore, the restriction on holding the Sections' offices other than Chairman and the Chairmanship of the Standing Committees of Sections shall not be operative until January 1, 1947."

It was unanimously approved that (b), as here submitted, be delayed in submission to the voting membership pending further advice from the Chairman of the Sections Committee. Approval was given to the proposal that (a) be submitted with the ballot to the voting membership.

Membership Solicitation Policy: A report was presented which included the following recommendation:

That the Sections be queried on the question of indicating in the YEARBOOK where a person had been a member at intervals of time, rather than indicating the last period of membership. It was unanimously approved that this recommendation be left to the Executive Committee for action.

The committee stated that it had discussed at length the question of broadening the base of the Institute to include technicians. Following the discussion, the committee had decided to inform the Board that the committee declined to make a recommendation on this question.

After a discussion by the Board on broadening the membership base of the Institute, it was moved that the Board ask the Membership Solicitation Policy Committee to consider, though not necessarily to adopt, a proposal that it is the policy of the Institute

(a) To add to its membership such technicians and other engineering workers as will readily derive benefit from the technically sound presentation of historical, tutorial, or current engineering data, and

(b) To endeavor to provide such Section and other activities, and publications, to the membership, as will be of assistance to the above-mentioned types of members.

This proposal was unanimously approved.

During the discussion of the broadening of the base, Mr. G. W. Bailey stated that, due to the small attendance at the committee meeting, and the many factors involved, he felt that the ground had not been adequately covered, and he accordingly advocated further consideration on the whole subject by a large group of the Board.

New Membership Solicitation Policy: The following appointments to the New Membership Solicitation Policy Committee were unanimously approved:

F. B. Llewellyn, *Chairman*
Alfred N. Goldsmith — Keith Henney
R. A. Heising — L. C. F. Horle
L. P. Wheeler

Nominations: It was unanimously approved that the Board proceed to ballot on the nominations proposed by the Nominations Committee.

The Board thereupon proceeded to ballot, with the following nomination result:

President: F. R. Llewellyn
Vice-President: E. M. Deloraine

Upon conclusion of balloting, the President declared the following six members nominated for Directorships: W. R. G. Baker, Walter Evans, R. A. Hackbusch, F. R. Lack, D. B. Sinclair, and W. O. Swinyard.

Professional Recognition: Chairman White presented the following recommendation, which was unanimously approved:

"Our Committee recommends that, for the present, the Institute confine its activities on collective bargaining to further study and the advising of its membership of the best available information on the subject, either sent in response to requests, or through publication of certain items in the PROCEEDINGS, or both. It also recommends that a committee continue actively to study the subject so that the Board may be informed or advised of any new developments that might make it desirable for the Institute to participate.

"It is further recommended that the Institute accept or seek representation on any committee studying the problem jointly in behalf of a group of recognized engineering societies."

Special Committee on Board Meetings: Mr. Heising, at the request of Mr. H. A. Wheeler, presented the recommendation, which also was unanimously approved.

"That the Special Committee on Board Meetings be authorized to send to the Board of Directors and to the Constitution and Laws Committee a draft of proposed amendments embodying the plan for regional representation, and the Constitution and Laws Committee be requested to prepare and to submit to the Board a final draft of the proposed amendments in a form suitable for action by the Board."

Executive Committee

June 6 Meeting: The Executive Committee meeting, held on June 6, 1945, was attended by W. L. Everitt, president; G. W. Bailey, executive secretary; S. L. Bailey, W. L. Barrow, W. H. Crew, assistant secretary and acting technical secretary; Alfred N. Goldsmith, editor; E. Finley Carter, R. A. Heising, treasurer; and Haraden Pratt, secretary.

Membership: The following actions were taken on matters presented by the Admissions Committee:

Test Case: It was unanimously approved that the policy with respect to applications for transfer or admission to membership from applicants dealing with the legal or related technical aspects of patents be as follows: Inasmuch as the proper public expression and legal protection of the technical advances originated by engineers do contribute to engineering and engineering welfare, and accordingly to the advancement

of engineering and science, the work of a patent attorney of suitable advanced grade and proved competence falls within the provisions of the Constitution covering the grade of Senior Member.

The following transfers and applications for membership were unanimously approved: For transfer to Senior Member grade, R. B. Albright, J. R. Bach, F. J. Bleil, W. R. Dresser, D. G. Fink, W. E. Gilbert, T. S. Gray, J. C. Herber, R. W. Hickman, J. B. H. Kuper, W. S. Lemmon, Roger McSweeney, Louis Malter, E. C. Manderfeld, G. H. Munro, J. A. Rado, D. S. Rau, H. E. Rice, J. B. Russell, F. W. Schor, M. L. Thompson, J. A. Wood, Jr., and J. D. Woodward; for admission to Senior Member grade, J. F. Byrne, R. V. Coles, R. H. Davies, W. E. Koch, and G. H. Phelps; for transfer to Member grade, George Abraham, D. E. Arnold, R. E. Bailey, G. E. Beggs, Jr., Robert Biedenbender, E. L. Brown, V. C. Campbell, W. S. Carley, H. J. Carter, E. L. Cave, J. H. Copp, S. C. Coroniti, G. F. Craig, R. P. Dimmer, G. F. Elston, F. J. Gaffney, George Glinski, A. L. Goeppinger, P. E. Grandmont, D. A. Heisner, C. F. Hobbs, K. B. Hoffman, R. H. Jones, Jr., M. J. Kobilsky, J. W. Koch, P. H. Kreager, R. P. Lett, Clair Lewis, B. T. McNeil, W. D. Montgomery, L. H. Naum, R. P. Owen, R. K. Phatak, J. W. Rabb, A. E. Richmond, A. J. Rohner, H. H. Schwartz, J. B. Sherr, C. E. Sturtevant, M. J. Werry, R. N. White, E. W. Yetter, and L. W. Zabel; for admission to Member grade, M. E. Ames, Jr., A. M. Bacon, H. L. Barney, L. E. Bessemer, I. S. Boak, E. S. Brotzman, H. R. Callahan, R. T. Capodanno, W. T. Carnes, Jr., Haing-Pao Chung, Nicholas Chako, R. A. Clark, Jr., W. P. Cole, R. W. Cushman, M. F. Davis, R. H. Edmonds, F. S. Fisher, Kenneth Glace, R. K. Haines, N. E. Handel, D. E. Hannum, M. T. Harges, Bernard Hecht, J. H. Henninger, D. F. Holshouser, H. N. Jacobs, Jack Kline, Shao-hsiung Kung, J. R. Lamgham, J. F. Lorber, Dah-You Maa, T. J. Mann, R. L. Mattingly, A. H. McRae, A. F. Miller, E. G. Miller, Jr., Sidney Moskowitz, Reuben Nathan, A. M. Okun, H. J. Oosterling, Ernest Pappenfus, W. E. Phillips, Jr., W. L. Pitts, J. H. Pomerene, S. J. Reisman, B. E. Schnitzer, W. E. Schuyler, Jr., Abe Shulman, R. R. Simons, S. S. Smith, D. H. Strangways, S. J. Sysko, C. C. Taylor, L. W. Thomas, R. L. Trent, F. R. Wagner, H. K. Warner, R. P. Watson, S. A. Westwood, and Bert Zarky; Associate grade, 158; and Student grade, 92.

Amendment to Sections Constitution: It was unanimously approved that Article II, Section 2, be amended to read as follows:

> "Sec. 2—All Fellows (Senior Members) Members, and Associates of the Institute residing within the territory of the Section shall be entitled to attend meetings, vote, and hold office, except that only members of Member or higher grade can hold the office of Chairman."

Committees and Appointments

New Technical Committees: It was unanimously approved that the following new Technical Committees be appointed:

- Research Committee: —
- Handbook Committee: H. A. Wheeler, *chairman*
- Medical Electronics Committee: G. W. Horton, *chairman*
- Railroad and Vehicular Communications: W. T. Cooke, *chairman*
- Industrial Electronics: —

and that the Constitution and Laws Committee be instructed to revise the third paragraph of the Bylaws, Section 46, to include these additional Committees.

Unanimous approval was given to the proposal that the name of the Radio Wave Propagation Committee be changed to "Radio Wave Propagation and Utilization Committee," and that the Constitution and Laws Committee be instructed to prepare an amended bylaw to be submitted to the Board.

Proposed Committee Personnel: The following appointments were unanimously approved:

ADMISSIONS

H. A. Chinn	J. C. Stroebel
A. R. Morton	F. D. Webster

ORGANIZATIONAL RESEARCH

S. L. Bailey	Saul Dushman
Ralph Bennett	E. W. Engstrom
Earl Cullum	J. W. McRae
L. A. DuBridge	D. B. Sinclair

PUBLIC RELATIONS

F. W. Albertson	E. M. Webster

NORTHWESTERN UNIVERSITY REPRESENTATIVE

R. E. Beam

SOUTHERN METHODIST UNIVERSITY REPRESENTATIVE

A. V. Stanton

Canadian Council: It was unanimously approved that the Executive Committee recommend to the Board that a certain, appropriate sum be transmitted to the Canadian Council to cover operating expenses for 1945.

Proceedings: Dr. Alfred N. Goldsmith reported that a further extensive study on the paper situation has been prepared for presentation to the WPB as an appeal and is in the hands of the General Counsel.

The papers bank for the PROCEEDINGS is in excellent condition. A report on the returns from the membership survey on papers has been turned over to the Papers Procurement Committee and indicates a satisfactory anticipated supply of papers.

Committee Personnel: The following appointments were unanimously approved for the Board of Editors:

Radio and Nonradio Law: A. W. Graf

Electronics, Methods, and Definitions: E. D. McArthur

The following appointments were unanimously approved:

Papers Procurement Committee; Subcommittee on Microwaves of Electron-Tube Group: R. M. Bowie

Home Receiver (Sound) Group: John Reid

Publication of "Standard Frequency Ranges": Mr. H. A. Wheeler requested the publication of "Standard Frequency Ranges" in the PROCEEDINGS, with the request for expressions from the membership, and this was approved. (See page 548.)

1946 Winter Technical Meeting: Mr. S. L. Bailey reported that Mr. E. J. Content had accepted the Chairmanship of the 1946 Winter Technical Meeting and already has most of his committee chairmenship acceptances; that because of a six months' definite limit, no application can be made to the Office of Defense Transportation until July; that reservations had been made at the Hotel Commodore for the ballroom floor for January 23–26, 1946, as a tentative action depending upon later approval of the Office of Defense Transportation.

I.R.E.-I.E.E. Co-operation

The Institute of Radio Engineers will be interested to learn of the plans of any of its members who expect to visit England. The Institution of Electrical Engineers, in London, has kindly expressed its willingness to arrange for members of the Institution to meet with I.R.E. members in England in cases where such individuals have interests in common. It is thus hoped to ensure, from the point of view of two societies, the most fruitful outcome of the opportunities afforded by these visits for a general interchange of views.

Members of the I.R.E. planning to visit England and desiring to make such arrangements should send the appropriate information to the Executive Secretary of the I.R.E., Mr. George W. Bailey at 330 West 42nd Street, New York 18, N. Y., for transmission to The Institution of Electrical Engineers in England. If possible, four weeks notice should be given.

New Patent Office Service

Commencing June 1, 1945, the United States Patent Office has put in operation a new service to industry and inventors. The purpose of the service is to bring to the attention of the nation patented inventions under which the owners are willing to grant licenses on reasonable terms; it is hoped that such information will lead to greater employment opportunities in the reconversion period, as well as permit industry to become acquainted with what is being done in various fields.

To accomplish the purposes set out above, a Register of Patents Available for Licensing is now being established, and will be maintained in the United States Patent Office. Patents recorded on this register will be available to the public for inspection in Washington, D. C. Lists of such patents will be published in the Official Gazette of the Patent Office; and it is hoped that engineering periodicals will be able, from time to time to publish selected lists applicable to their fields.

The viewpoint of the I.R.E. membership relative to such publication would be of interest to the Institute's Editorial Department.

Report of the Standards Committee Relating to Standard Frequency Ranges

During the past few years, the increasing use of higher radio frequencies has made it desirable to divide the frequency spectrum into frequency ranges with standard designations, in order to obviate the use of such indefinite terms as "short-wave," "long-wave," etc. There have been several suggestions for the required terminology. These have been reviewed by the Standards Committee and the accompanying table entitled "Standard Frequency Ranges" is submitted as a reasonable solution to the problem.

STANDARD FREQUENCY RANGES

Range Number N	Frequency Range: Lower Limit (exclusive)	Frequency Range: Upper Limit (inclusive)	Wavelength Range: Lower Limit (inclusive)	Wavelength Range: Upper Limit (exclusive)	Wavelength Range Designations	Frequency-Range Designations
0	0.3 c	3 c				
1	3 c	30 c				
2	30 c	300 c				
3	300 c	3 kc				
4	3 kc	30 kc	10 km	100 km	ten-kilometer	very-low-frequency (v-l-f)
5	30 kc	300 kc	1 km	10 km	kilometer	low-frequency (l-f)
6	300 kc	3 Mc	1 hm	10 hm	hectometer	medium-frequency (m-f)
7	3 Mc	30 Mc	1 dkm	10 dkm	dekameter	high-frequency (h-f)
8	30 Mc	300 Mc	1 m	10 m	meter	very-high-frequency (v-h-f)
9	300 Mc	3 kMc	1 dm	10 dm	decimeter	ultra-high-frequency (u-h-f)
10	3 kMc	30 kMc	1 cm	10 cm	centimeter	super-high-frequency (s-h-f)
11	30 kMc	300 kMc	1 mm	10 mm	millimeter	

Adjective for Nth range = Nth-range frequency.

A few years ago, the Armed Forces adopted a series of names and abbreviations covering seven decades of the radio-frequency spectrum. These appear in the last column of the accompanying table. These were in turn adopted by the Interdepartment Radio Advisory Committee and the Federal Communications Commission. They have been used in many publications.

In October and November, 1943, the Standards Committee considered these terms and, by a large majority, voted that they were not considered suitable for adoption by The Institute of Radio Engineers.

Recently this subject has been reconsidered by the Standards Committee with due attention to this and other terms for designating the various ranges of the frequency spectrum. There was general agreement that a decade system of frequency ranges is a logical and satisfactory method of subdividing the frequency spectrum. There was no unamimity favoring any one set of terms for these ranges. The accompanying table gives the two sets of terms which were considered satisfactory by a majority of the committee. Other designations which were proposed met with considerable disfavor within the committee and therefore were discarded.

The proposed system divides the frequency spectrum into decade ranges with boundaries which are convenient numbers expressed in terms of frequency and wavelength. The designation of each wavelength range is merely the name of the metric unit of length which is equal to the wavelength at the lower limit of the range. The designation of each frequency range is the term adopted by the Armed Forces. In addition, each decade is given a range number which may be used as a short designation.

The table is based on the approximation that the wave velocity is 300,000,000 meters per second. In any case where the required precision makes this assumption inadequate, the exact boundaries of the ranges should be based on the frequency range, not the wavelength range.

This table has been adopted as a standard of the I.R.E. As such it is recommended for general use. At the same time, any comments by way of criticisms or further suggestions relating to this problem are welcome. They should be addressed to the Chairman of the Standards Committee in care of the Institute of Radio Engineers, 330 West 42nd Street, New York 18, N. Y.

Harold A. Wheeler
Chairman, Standards Committee 1944–1945

Frequency-Modulation Committee of FCC

The United States Federal Communications Commission, through its chief engineer, George P. Adair, recently invited a group of engineers to serve as a committee to work with the Federal Communications Commission staff in conducting further tests on frequency-modulation transmission in the 44- to 108-megacycle band throughout the summer months, preliminary to a final allocation of frequencies to this service. Among those invited to serve on the committee were the following members of The Institute of Radio Engineers:

Major Edwin H. Armstrong (A'14–F'27)
Professor of Electrical Engineering
Columbia University
New York, N. Y.

Dr. D. E. Noble (A'25–SM'44)
Director of Research and Communications
Galvin Manufacturing Corporation
Chicago, Ill.

Dr. W. R. G. Baker (A'19–F'28)
Vice-President
General Electric Company
Bridgeport, Conn.

Dr. T. T. Goldsmith (A'38)
Allen B. Du Mont Laboratories, Inc.
Passaic, N. J.

Raymond Guy (A'25–M'31–F'39)
National Broadcasting Company
New York, N. Y.

Dr. William B. Lodge (A'34–M'37–SM'43)
Columbia Broadcasting System
New York, N. Y.

David B. Smith (A'35–SM'44)
Director of Research
Philco Radio and Television Corporation
Philadelphia, Pa.

C. M. Jansky, Jr. (A'18–M'25–F'28)
Jansky and Bailey
Washington, D. C.

Everett Dillard (A'38)
Commercial Radio Equipment Company
Washington, D. C.

Dr. Harold H. Beverage (A'15–M'26–F'28)
R.C.A. Communications, Inc.
New York, N. Y.

Dr. Charles R. Burrows (A'24–M'38–SM'43–F'43)
Civil Committee on Propagation
National Defense Research Committee
New York, N. Y.

G. F. Leydorf (A'36–SM'44)
Crosley Corporation
Cincinnati, Ohio

Cyrus T. Read (A'43)
The Hallicrafters Company
Chicago, Ill.

D. C. Summerford (A'39–M'44)
Assistant Technical Director, WHAS
Louisville, Ky.

J. R. Poppele (A'30–M'39–SM'43)
WOR, Bamberger Broadcasting Company
New York, N. Y.

Frank Marx (A'41)
The Blue Network
New York, N. Y.

Dr. H. W. Wells (A'36–M'36–SM'43)
Carnegie Institute of Washington
Washington, D. C.

G. E. Gustafson (A'27–M'38–F'40)
Vice-President in Charge of Engineering
Zenith Radio Corporation
Chicago, Ill.

Frank A. Gunther (A'25–M'30–SM'43)
Vice-President in Charge of Engineering
Radio Engineering Laboratories, Inc.
Long Island City, L. I., N. Y.

Robert Higgy (A'26)
WOSU
Columbus, Ohio

Carl H. Wesser (A'41–M'42–SM'43)
Chief Engineer, WENA
Detroit, Mich.

Public Relations Committee

The Public Relations Committee of the Institute held a meeting in Washington on Monday, May 7, 1945 in the offices of Jansky and Bailey, there being present: I. S. Coggeshall, chairman; O. B. Hanson; G. W. Bailey, executive secretary; C. M. Jansky, Jr.; Commissioner E. K. Jett; A. F. Van Dyck; S. P. McMinn, representing O. H. Caldwell; and R. F. Guy, guest.

The Committee acted, by request of the Board of Directors, in recommending a legislative program for the Institute.

It was the consensus that the bestowal of the Institute's War Service Awards should be deferred until a more propitious time for the selection of those to be honored.

The need was stressed for the Institute office to undertake, as soon as professional talent is engaged in connection with the society's expanding program, the release of publicity items and photographs to the press. The Committee voted to recommend that technical items be made a prominent feature of such releases, following the plan so successfully used by the National Geographic Society in its series:

"According to the National Geographic . . ."

A suggestion was made that it would be appropriate for the Institute, from the viewpoint of its public relations, to take a technical position in connection with the use of frequencies for low-power devices, devices on the border line of radio transmission and inductive coupling, diathermy, inductive heating, and the like, with regard to licensing as a control against interference with other services.

The Committee will give further attention to a project of popular lectures, to be sponsored by Institute's Sections, designed to tie the Institute more closely to the public.

First I.R.E. International Convention Fifteen Years Ago

On August 18–21, 1930, the first international convention of The Institute of Radio Engineers was held in Toronto, Canada. This was also the fifth annual convention of the Institute. During that year, the President of the Institute was Dr. Lee de Forest.

The meeting was also of major interest in that there was conducted a joint meeting of the I.R.E. and of the engineering division of the Radio Manufacturers Association. A number of instructive papers dealing with manufacturing problems were presented at the time. The Toronto Section of the Institute had already been active for five years.

Among the prominent members of the Institute who were active in the first International Convention were, on the Convention Committee, R. A. Hackbusch, A. B. Oxley, and K. S. Van Dyke; on the Exhibition Committee, Virgil M. Graham and I. G. Maloff; on the Ladies' Committee, Mrs. R. A. Hackbusch; on the Membership and Fellowship Committee, C. P. Edwards and L. C. F. Horle; on the Publicity Committee R. A. Hackbusch, O. E. Dunlap, and Donald McNicol; and on the Banquet and Entertainment Committee, A. B. Oxley and F. P. Guthrie.

In the fifteen years following the first I.R.E. International Convention in Toronto, additional Sections of the Institute have been formed in Canada, and the membership has multiplied greatly. An important new group, the Canadian I.R.E. Council, has been formed to represent the I.R.E. membership in Canada in matters affecting their relationship with the Canadian Government and in certain similar matters. The growth of the Canadian I.R.E. activities, and their steady increase in scope and value to the profession, have been a source of added strength to the Institute. The essential solidarity of the Canadian membership of the Institute and its other membership groups is a fortunate indication of the international nature of science and of the friendly relationships existing between these groups.

Dana Bacon

Friends of Dana Bacon were saddened to learn of his death on May 24, 1945. He was held in deep affection by all those who worked with him and was consulted on personal problems as well as technical ones. Mr. Bacon gave advice freely to all who requested it and carried on a large correspondence with amateurs all over the country.

Dana Bacon

He was born on December 23, 1905, and was graduated from Northeastern University in 1926 with the B.E.E. degree. He was with the Boston Edison Company in their instrument testing laboratory before going to the National Company in Malden, Massachusetts, where he was for the past twenty years and where he was chief electrical engineer at the time of his death. He was an active radio amateur and developed many radio circuit features including crystal filters, radio-frequency coupling circuits, noise limiters, etc.

Mr. Bacon joined the Institute as an Associate in 1931. He was a member of the Papers Committee for one year and vice-chairman of the Boston Section one year.

Wallace B. Caufield, Jr.

By direction of the President of the United States, a Bronze Star Medal for meritorious achievement in connection with military operations against an enemy of the United States during the period indicated has been awarded posthumously by the War Department to Wallace B. Caufield, Jr., an American civilian.

The citation reads as follows:

"During the period from November, 1944, to January, 1945, Mr. Caufield served with the Headquarters Ninth Air Force, Advanced, as civilian advisor on matters pertaining to radio counter measures. He also served in both the Mediterranean and European Theaters of Operation, often in forward combat areas in order to obtain first-hand information and to advise the commanders of advanced units on matters relating to radio counter measures. Although a civilian, and not required to expose himself to the hardships of field conditions, he lived in the field during a large part of his association with the Ninth Air Force, and, of his own volition, subjected himself to all the dangers of combat. By accepting such additional risks he was able to obtain valuable information and to offer more significant advice than would have been possible otherwise. His efforts contributed materially to the planning, training, and execution of an important technical program of the Ninth Air Force.

Date of the award 30 April 1945, European Theater."

Mr. Caufield was an Associate Member of the Institute.

Engineer Talks on Crystals

In a paper delivered before the Rochester, New York, Section of I.R.E. on April 19, 1945, A. A. Leonard (A'41) of North American Philips Company, Inc., covered some interesting points concerning present and future problems in quartz crystal application.

A few matters discussed were piezoelectric effect, electromechanical coupling, lattice, axes (including imaginary *Y*), coupling between modes of vibration, manufacturing tolerances, equivalent circuits, "Miller" effect, frequency standards, and a suggested "figure of merit."

Speaking of the future, Mr. Leonard said, "Peacetime requirements may also be very large. At least two manufacturers of receivers for the broadcast band are much interested in using crystals to stabilize push-button tuning. Frequency-modulation receivers, crystal-tuned, have been built, and crystals appear to be a very practical way to solve the difficult problem of tuning. Television receivers will probably be crystal tuned.

"Since the crystal moves mechanically, it can be used to generate mechanical vibrations at radio frequencies, or 'supersonic' waves. They will be used to emulsify, demulsify, and homogenize chemicals and foods and to control bacterial and crystal growth."

Correspondence

Radio-Noise-Meter Performance

Since radio-noise-meter performance is a matter of keen current interest, and since many people have attached considerable weight to the results of Mr. Charles M. Burrill's tests, I should like to raise some questions concerning his study, "An Evaluation of Radio-Noise-Meter Performance in Terms of Listening Experience" in the October, 1942, issue of the PROCEEDINGS.

These remarks are meant to point to certain pitfalls in conducting listener tests, and not to reflect on the quality of Mr. Burrill's research. In fact, Mr. Burrill is to be commended for using psychological techniques and especially for his fruitful application of statistical methods to a problem in engineering research.

Mr. Burrill has found a high degree of relationship between noise-meter measurement and listener judgment of disagreeableness of sound. In so doing, he used a six-point rating scale, on which listeners could register their feelings. The scale ranged from *A* (entirely satisfactory) to *F* (speech unintelligible). On the basis of his finding, he implies that the meter can be substituted for subjective experience, or in other words, that subjective feeling can be predicted from meter readings. This is a valid conclusion provided that predictions of subjective experience from the meter readings are made only in terms of the six-point scale used in the research.

Recently, however, engineers have attempted to apply the meter to a use which goes beyond the limitations of Mr. Burrill's research, that is, to determine the exact amount of interfering noise where agreeableness ends and disagreeableness begins. Such an extension cannot be made from Mr. Burrill's data because his rating scale does not define such a point. The threshold of just noticeable disagreeableness may lie on his scale anywhere between *B* (very good, background unobtrusive) and *D* (background very evident, but speech easily understood). How much of the background listeners will tolerate still remains an open question.

Additional research is required to answer this question. The rating scale may be useful to establish general relationships but it cannot be used for certain specific problems like the one cited above. Instead, once the relationship has been established, other techniques must be employed to determine the point of disagreeableness. For this purpose, two standard methods used in experimental psychology are available:

(*1*) *Paired comparisons*—Different noise conditions are presented to the listener in alternate pairs. All the listener has to do is indicate which of the two conditions he prefers, or finds less objectionable. The experimenter introduces enough different paired conditions so that he can determine the exact point at which interference becomes just noticeably disagreeable (or any other criterion desired).

(*2*) *The method of limits*—A radio program can be played at a relatively constant sound intensity, while the listener controls a dial which introduces more or less interfering noise at will. The listener is instructed to turn the dial back and forth until he reaches the point of just noticeable disagreeableness. Research with this technique has shown that while the listener will not always arrive exactly at the same point each time, he usually comes pretty close. An average of several readings proves to be rather reliable. This is probably a better technique than the first because it is likely to yield a more accurate statement of the threshold of disagreeableness. In addition, for a completely satisfactory test certain other requirements must be met: (1) A larger number of subjects than the 30 used by Mr. Burrill is needed to assure an adequate sample and to study individual variation. (2) The subjects should be a cross section of radio listeners, since engineers and technical people, because of their specialized training, often react quite differently from average listeners. (3) A larger variety of interfering noises, as well as types of radio material should be used, since the point of disagreeableness may vary with type of noise and with program content.

It is noteworthy that engineers are becoming more aware of the need to study listener reaction, and that they are using psychological techniques in their research. However, just as different meters are suitable for different purposes, psychological instruments vary in their usefulness. Subjective feeling must be as carefully measured as the physical characteristics of sound. In listener tests, the listener must be given an opportunity to make an objective judgment. The situation must be so arranged that the listener can make a decision with ease and with complete self-confidence.

PHILIP EISENBERG,
Research Psychologist
Columbia Broadcasting System
New York 22, N. Y.

Professional Status of the Engineer

The following comments are intended in connection with the several stimulating articles on the professional status of the engineer which appeared in the May, 1945, PROCEEDINGS.

Too close a comparison between the status of the lawyer, the doctor, and the clergyman and that of the engineer cannot properly be made, since the former meet problems which are not uniform in nature and must be solved individually, the solution also being unique, so far as the client is able to determine. Furthermore, there are often strong subjective motives which lead the client to seek expert advice. The engineer is frequently called upon to solve the same problem for several million people; his solution, when given, is often capable of unlimited application and is subject to objective criticism. The linen of the engineering profession is almost inevitably on exhibition to the public while that of the doctor and the lawyer is carefully kept in the laundry as a matter of custom and principle. It thus appears impossible and is probably undesirable that the engineering profession ever enjoy the uncritical respect which is accorded the others. Accurate but simple interpretation of the engineering profession to the public seems the prime essential to its elevation in public esteem. Despite the sincere efforts by many of the larger journals to maintain a reasonable standard of accuracy in writing on technical subjects, active co-operation by local units of national professional organizations could do much to reduce misinterpretation of legitimate news and to permit appropriate evaluation and disposition of the inflated claims to glory which even organizations having outstanding commercial research laboratories frequently release through publicity channels. The Executive Secretary of the Institute should be able to offer helpful comment in this connection.

If, as a preliminary to a formal appearance before the public, the profession requires a definition of engineering, I suggest the one originally sponsored, I believe, by the United Engineering Trustees: "Engineering is the science of controlling the forces and utilizing the materials of nature for the benefit of man, and the art of organizing and directing human activity in connection therewith." The use of the word "science" prevents this definition from including too much; no man is a scientist who does not know the boundaries which differentiate the experimentally demonstrable facts which he knows, from the empirically acquired rules which must be employed only subject to experimental confirmation of their adequacy in the particular case.

If engineering is to achieve general recognition as a profession, the best possible methods for selecting engineering students will be no more than adequate. I consider it unfortunate that the choice of engineering as a curriculum is frequently made when the student is still in the process of adjusting himself to the obligations of maturity. To some youths the immutability of physical laws appears to offer a tempting refuge from the vagaries of human behavior. He enters upon a course of engineering studies, and graduates to find that success in engineering requires just as much skill in the conduct of personal relationships as does any other field of endeavor, or that his clarified view of his environment enables him to see that his true interest is in another direction. Such men too frequently become the Micawbers of the profession. They constitute a definite problem whose solution will probably baffle directors of admission to engineering schools for some time to come.

HENRY W. KAUFMANN
1636 Abingdon Drive
Alexandria, Virginia

Growth of Electronics in the Fleet Personnel of Electronics Division Bureau of Ships*

(A Communication from the United States Navy Department)

As an index of the growth in importance of electronics to our fleet, an interesting comparison recently came to light of the personnel engaged in planning the design, procurement, production, distribution, installation, and maintenance of electronic equipment in the current war and in World War I.

At the time of the World War I armistice, the total staff of the then "Radio Division" which was established in 1910 numbered 75 officers and 25 civilians. As of April 1, 1945, the staff of the Electronics Division now under the direction of Commodore (then Captain) J. B. Dow, United States Navy, has grown to 1160, composed of 459 officers, 487 civilians, and 214 WAVES. Just prior to December 7, 1941, the total division personnel number was 107. In other words, the present personnel is sixteen times as large as the World War I group, and over eleven times as large as the personnel in the period just before our entry into the war in 1941.

It is also interesting to note that the World War I organization included three primary sections, Ship, Shore, and *Aircraft*. The emphasis on aircraft as early as 1917 indicates the Navy's strong interest in aviation as applied to naval science, and explains why the United States Navy has always led the way in the development of Naval aviation. The tremendous accomplishments of our naval air arm of today are possible in large measure as a result of the interest and pioneering work of naval personnel at the time of World War I and during the "twenties." Airborne electronics have kept pace with the communication and other military requirements of modern naval aircraft. Our planes are equipped with the finest and most versatile electronic equipment in the world.

The scene is laid off the coast of a tropical island in the Pacific Ocean. A vast fleet of battleships, cruisers, destroyers, and carrier planes has just completed the initial bombardment of enemy installations on the island and the moment has arrived for the first assault waves to move in. For several miles opposite the island may be seen dozens of specially designed attack transports, for brevity labeled merely "APA," and "LST," which the Navy translates as "Landing Ship Tank," all unloading their cargoes of smaller landing craft. Among these are numbered hundreds of LCT's which are to carry troops and tanks to the beach. The operation proceeds like clockwork, the LCT's moving in perfect formation through the choppy water and the surf until they hit the beach. They have all the appearance of being guided in every movement from some central location and this is actually the case. The LCT's are being controlled and directed by means of two-way voice radio equipment installed in each one and at the control point in one of the larger transports or LST's.

An operation of this magnitude requires the closest co-ordination of movement. If the fleet of LCT's heading for the beach should be attacked by dive bombers, those under attack will radio for assistance and carrier-based fighter planes will be promptly sent in to drive off the attacking enemy planes. If one of the LCT's should unfortunately strike coral rock or some other type of shoal, it becomes a vulnerable target for the enemy's island gun emplacements. The radio can be used in a case of this kind to call for prompt assistance. If there are any injuries among the personnel of the LCT during the run to the beach, radio is used to call for another vessel to come along side and take off the wounded. Upon lowering the ramp at the time of hitting the beach, the LCT group commander may order the vessel by radio to return to the transport to pick up another load. The two-way radio used in this vast fleet of LCT's, LST's, APA's to maintain such close immediate radio communication is known as a TCS, a very versatile standard Navy transmitter-receiver.

It is well to stop and think a minute about how this large fleet of landing craft came to be equipped with this fine radio equipment; by what means were these thousands of TCS equipments produced and installed so that at this precise moment of invasion in the far reaches of the Pacific, thousands of miles from the points of their manufacture, they would be ready to serve so usefully and to add so materially in the conquest of an enemy-held island?

As explained by Commander Palmer K. Leberman, United States Naval Reserve, who directs the Navy's electronic-equipment production and distribution organization, the steps involved in the supply of electronic equipment are generally as follows:

The story begins in a consideration of the strategy of the Pacific war when it has been determined by the Commander-in-Chief that the operation just described is necessary. The operation is evaluated in terms of the number and types of ships required to put the estimated number of troops and equipment ashore at a certain time on a certain date. The Navy then requests authorization from Congress for the construction, where necessary, of additional vessels and the necessary landing craft to carry out the operation. In the case under consideration, the Bureau of Ships would receive authorization for the construction of a large number of LCT's. It would then arrange with a shipbuilding concern, or several, to construct the required number of LCT's on a carefully arranged schedule of completions each month so that the total number will be ready when needed. At about this time the Chief of Naval Operations would direct the Bureau of Ships to produce and install on each of the required LCT's one 25-watt radiotelephone transmitter and suitable receiver capable of providing two-way voice communication while en route from the transport to the beach. This directive would set forth the act that the required radio equipment should provide reliable communication even when used under adverse weather conditions, heavy static, and rough seas. The Electronics Division of the Bureau of Ships studies the directive and determines that the model "TCS" equipment, a standard design in the Navy for years, will meet the desired military characteristics as set forth by the Chief of Naval Operations. The Electronics Division then determines the number of TCS's required and the production rate per month to meet the authorized shipbuilding schedule. Procurement is requested and the Contract Division of the Bureau of Ships arranges with one or more manufacturers to produce the required number of TCS's. The manufacturers, if unable to meet the desired production schedule due to difficulty in obtaining required components, such as resistors and capacitors, requests assistance of the Electronics Division, which assigns production specialists to the job of expediting delivery of components from supplies to the TCS manufacturers.

If the completion date for the landing craft approaches, the Inspector of Naval Material arranges for shipment of the TCS's in accordance with instructions from the Electronics Division to the desired destination. The Resident Inspector of Naval Material, at the manufacturer's plant, is supplied full information which permits him to deliver equipments where and when they are needed so that sufficient interval will be available to complete installation of the equipment at the same time the LCT is completed. The equipment is shipped by railway express and arrives at the warehouse of the Radio Materiel Officer in charge of the activity at which the ship is being constructed. Meantime, the Radio Materiel Officer has completed all cabling and mechanical mounting for the installation of the equipment. Upon delivery of the TCS to the spot where the LCT is building, the Radio Materiel Officer has his staff of radio technicians make the installation and test it during the shakedown run of the vessel. After rigorous testing and indoctrination of the crew members who are to operate the equipment, the LCT, complete in every detail, is delivered to a seacoast port where it is loaded aboard LST's or APA's for transport across the ocean.

It will be seen from this description of the administrative work involved, that the presence of these TCS's aboard the LCT's at the moment of invasion is not due to accident or happenstance but is the end result of a tremendous amount of careful planning and close co-ordination.

Incidentally, the LCT if not too seriously damaged will be used in many other landing operations on near-by islands and beaches. Its TCS equipment must be maintained in tiptop operating condition at all times. To accomplish this the LCT carries a set of equipment spares consisting of all of the small replaceable items such as tubes, resistors, and capacitors. Should its quota of equipment spares be used up, the LCT requests replacements from a tender or repair ship. The tender or repair ship in turn replaces its spares from the nearest larger land base or supply depot. The advanced supply depots, of course, replenish their stocks from the West Coast mainland stock pool at the Naval Supply Depot, Oakland, California. By means of careful planning, the Electronics Division of the Bureau of Ships is able to determine the required rate of flow of maintenance parts and replacement equipments so that the electronic equipment used by the fleet is maintained in constant efficient operating condition and ready for instant use.

* Received by the Institute, April 23, 1945.

I.R.E. People

RAY H. MANSON

STROMBERG-CARLSON APPOINTMENTS

At the annual meeting of the Board of Directors of the Stromberg-Carlson Company, held on April 18, 1945, Ray H. Manson (M'23–F'30) was appointed president; George R. Town (A'37–SM'44) assistant secretary and manager of engineering and research; and Lee McCanne (A'36) vice-president and general manager of the organization.

Dr. Manson was born in Bath, Maine, on August 25, 1877, and was graduated from the University of Maine in 1898. He was awarded the degree of Doctor of Engineering in 1933. He was associated with the Western Electric Company, the Kellogg Switchboard and Supply Company, both in Chicago, and the Dean Electric Company, and Garford Manufacturing Company, in Elyria, Ohio, before he joined the staff of the Stromberg-Carlson in 1916, as chief engineer. In 1920 he was elected a director of his firm, becoming vice-president in charge of engineering in 1924, and general manager in 1940. He is one of the nation's leading authorities in the field of communications, and creator of more than 100 inventions in this field. He was President of The Institute of Radio Engineers in 1931. He is a director of the Radio Manufacturers Association, and executive committee member of the association's set division and representative of that organization on the administrative committee of the Radio Technical Planning Board. Dr. Manson is also a Fellow of the American Institute of Electrical Engineers, a Fellow of the Radio Club of America, a Member of the Acoustical Society of America, the Rochester Engineering Society, and the American branch of the Newcomen Society of England.

GEORGE R. TOWN

Dr. Town was graduated from Rensselaer Polytechnic Institute in 1926, receiving his doctorate from the same institution in 1929. Before beginning his association with Stromberg-Carlson, he worked as research and development engineer at Leeds and Northrup Company, in Philadelphia, Pa., and at the Arma Engineering Company, in Brooklyn, N. Y. From 1933 to 1936, he was instructor in electrical engineering at Rensselaer Polytechnic Institute. In 1936 Dr. Town became an engineer in the research laboratory of the Stromberg-Carlson Company, and in 1940, was made engineer in charge of the company's television laboratory. He was appointed assistant director of research in 1941, and manager of research and engineering in 1944. Dr. Town has represented his organization on various television standardization committees of the National Television System Committee and the Radio Technical Planning Board. He is secretary of the television panel of that Board, and chairman of the television standards committee, in addition to filling the post of chairman of the frequency-modulation systems committee of the Radio Manufacturers Association. He is chairman of the Rochester Section of The Institute of Radio Engineers, and treasurer of the Rochester section of the American Institute of Electrical Engineers.

LEE McCANNE

Mr. McCanne was born in St. Louis, Missouri, in May, 1905, and was graduated from Massachusetts Institute of Technology in 1927. Upon receiving his B.S. degree he joined the staff of the Stromberg-Carlson Company as a radio engineer. He transferred to the sales department in 1931, becoming radio sales manager in 1934. He was appointed a director and secretary in 1934, and assistant manager in 1940.

Mr. McCanne is vice-chairman of the Committee for Economic Development in the Second District of New York State, regional director for the National Federation of Sales Executives, vice-president of the Electrical Association of Rochester, a trustee of the Rochester Chamber of Commerce, vice-chairman of the School Sound Systems Committee of the Radio Manufacturers Association, and is active in civic and social organizations. He is a member of the Rochester Engineering Society and the Independent Pioneer Telephone Association.

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ROYAL V. HOWARD

Royal V. Howard (M'41–SM'43), who has recently returned to San Francisco after a year's leave of absence for overseas duty in the European Theatre of Operations for the United States Army, has been elected vice-president in charge of engineering for both the Associated Broadcasters, Inc., and the Universal Broadcasting Company of San Francisco, California. Announcement of his appointment was made on May 17, 1945.

Mr. Howard headed a special scientific staff in London and Paris, working through the Office of Scientific Research and Development. He was hospitalized as a result of enemy action, and returned to the United States the first of this year.

ROYAL V. HOWARD

O. S. Duffendack

One of the early pioneers in short-wave and aircraft communications, Mr. Howard's participation in radio dates back 20 years. During the last 12 years, he has been director of engineering for KSFO, KWID (a 100,000-watt international broadcast station), and KWIX, a 50,000-watt international broadcast station. Since his return from the Armed Forces, he has been elected director of engineering for the 10,000-watt station KPAS, in Pasadena, California. During the past 10 years he has been active in the radio industry. One of his most recently granted patents is for a robot monitoring system for radio stations, in use on KSFO for several years.

Mr. Howard is vice-chairman of the San Francisco section of The Institute of Radio Engineers, radio representative for the combined engineering societies, a member of the International Committee of the Board of War Communications, and former district engineering director for the National Association of Broadcasters. He is also a member of the national Radio Technical Planning Board's Panel 8, on International Broadcasting, and its Panel 4, on Standard Broadcasting.

O. S. Duffendack

O. S. Duffendack (SM'44), director of research of the North American Philips Company, Inc., was appointed vice-president and director of engineering of that company on June 15, 1945. Dr. Duffendack who will be responsible for all research and engineering activities, formerly was professor of physics at the University of Michigan. During the war, he was a director of research with the National Defense Research Committee and serves as chief of one of its sections.

Murray G. Crosby

Murray G. Crosby (A'25–M'38–SM'43–F'43) has joined the firm of The Paul Godley Company, Consulting Radio Engineers, Upper Montclair, New Jersey. He will specialize in radio-communication systems, including frequency-modulation problems, development projects, point-to-point mobile and air-borne communications, relay transmission, and satellite stations.

Mr. Crosby has been a research engineer for the communications division of RCA Laboratories for the past 20 years. In that position he specialized in frequency modulation and has over 100 patents, among them being the reactance-tube automatic-frequency-control type of frequency modulator used in frequency-modulation transmitters. He is the author of a considerable number of basic technical articles on the subjects of frequency and phase modulation.

Born in Elroy, Wisconsin, in 1903, he attended the University of Wisconsin receiving the B.S. degree in 1927 and his professional electrical engineering degree in 1943.

In 1940 he received a Modern Pioneer Award from the National Association of Manufacturers for contributions which improved the American standard of living. In 1943 he was vice-chairman of the New York Section of the Institute of Radio Engineers. He is a member of the 1945 Papers Committee, the Papers Procurement Committee, the Admissions Committee, and the Technical Committee on Frequency Modulation. He is also a Fellow of the Radio Club of America and a Member of the American Institute of Electrical Engineers.

In 1943 and 1944, Mr. Crosby served as expert technical consultant to the Secretary of War and received official commendations for his work.

Murray G. Crosby

Howard S. Frazier

Official Citation for Howard S. Frazier

Elmer Davis, Director of the Office of War Information, in a letter sent during the week of June 8, 1945, to Howard S. Frazier (M'43–SM'43), NAB Director of Engineering, who has been on part-time loan to OWI since November, 1944, commended the latter for his services in the recruitment and training of technical personnel for OWI overseas radio operations.

Employed by OWI only after release from broadcast stations, necessary experienced supervisory personnel were given advanced training at Bethany, Ohio, where several OWI international transmitters are located. Here they were put through a course of indoctrination and gained actual experience on high-powered transmitters. Many of the men were recruited from radio manufacturers. Extensive training of new personnel provided manpower without drawing heavily on domestic broadcast stations. Mr. Davis' letter follows:

"I wish to express my thanks to you for the very valuable services you have rendered this agency in helping us to solve one of our most difficult recruitment problems. With your co-operation and that of the National Association of Broadcasters, which has made your services available, the recruitment of technical personnel for our radio operations overseas has been greatly speeded up.

"I am glad that we shall continue to profit by your advice and counsel as we continue the job of meeting our overseas requirements."

I.R.E. People

James D. McLean

Paul Chamberlain and James D. McLean

Paul L. Chamberlain (A'43) was recently appointed manager of sales for the receiver division of the General Electric Company's electronics department, according to an announcement by I. J. Kaar (J'22–A'24–M'29–F'41), division manager; and James D. McLean (A'43) was appointed manager of sales for the transmitter division of the same organization, by C. A. Priest (A'24–M'38–SM'43), division manager. Mr. Chamberlain and Mr. McLean will have their headquarters at Bridgeport, Conn., and Schenectady, N. Y., respectively.

Mr. Chamberlain attended Washington University, St. Louis, Mo., and was first employed by the Century Electric Company of that city, where he became manager of the home office. He then engaged in laboratory and sales work for the Colin B. Kennedy Corporation, and later was employed by the Brunswick Phonograph Company as district manager. For the next ten years, Mr. Chamberlain supervised district sales of radio receivers for a number of firms, eventually becoming radio sales manager for the Ochlitree Electric Company, General Electric distributor at Pittsburgh.

In 1942 he entered the electronics department of the General Electric Company, and was placed in charge of the Army aircraft section of the government division, transferring in 1943 to the position of manager of sales for the transmitter division.

Mr. McLean is a graduate of the Massachusetts Institute of Technology, where he received the B.S. and M.S. degrees in electrical engineering. He became associated with the General Electric Company in 1935, as a student engineer. In 1936 he was engaged as radio engineer by the Republican National Committee during the presidential campaign, and in 1938 returned to the General Electric Company as a development engineer in the laboratory of that organization. Mr. McLean transferred to the electronics department in 1939, first as a design engineer in the transmitter division and later as co-ordinator of Army radio and radar equipment in the government division.

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R. Edward Stemm

R. Edward Stemm (M'44) will direct the sales activities of Communication Parts, Chicago, Illinois, according to a recent announcement. The organization will produce radio coils, solenoids, and other radio and electronic components, and carry out original design and consultation work.

R. Edward Stemm

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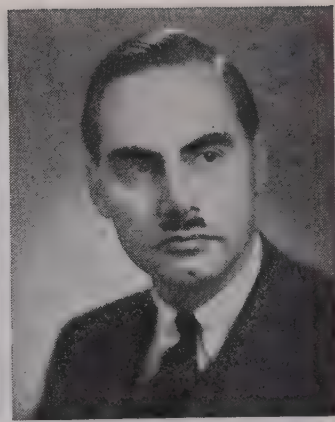
Henry S. Dawson

The appointment of Henry S. Dawson (A'35–SM'45) as chief engineer of the Canadian Association of Broadcasters was announced on May 3, 1945. Officials of the Association, at their annual meeting, had expressed the view that the rapid technical development of the broadcast industry necessitated the creation of the new post.

Mr. Dawson has already assumed his new duties, and will be responsible for studying data and research on national and international activities in the broadcast industry. He will advise the Association on all technical matters connected with the present broadcast structure, together with developments in frequency modulation and television. Mr. Dawson will also be the technical member representing the Canadian Association of Broadcasters on the Canadian Radio Technical Planning Board.



John Palmer

Henry S. Dawson

Mr. Dawson is a graduate of Cornell University in electrical engineering, and has previously been associated with the Canadian Marconi Company, Rogers Radio Tubes, Ltd., and station CFRB. Since November, 1940, he has served with Research Enterprises, Ltd., as project engineer and, later, as assistant chief engineer.

He is a member of the Association of Professional Engineers of Ontario, and was chairman of the Toronto section of the Institute of Radio Engineers in 1940 and 1941.

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Gomer L. Davies

Gomer L. Davies (M'33–SM'43) has announced his entrance into the field of consulting radio engineering. He offers a consulting service for broadcast stations on standard, high-frequency (frequency-modulation), and television problems, as well as some phases of electronics and aviation radio.

Mr. Davies has a background of twenty-three years of training and experience in antennas, directional arrays, and wave-propagation work, and in development, design, and production of specialized radio and electronic equipment in the aviation field.

Books

The Radio Amateur's Handbook (Twenty-Second Edition)

Published (1945) by The American Radio Relay League, Inc., West Hartford, Conn. 504 pages+200-page catalogue+12-page index+viii pages. 2107 figures. $6\frac{1}{2}\times9\frac{1}{2}$ inches. Price, $1.00.

Such changes as have been made in the twenty-second edition of the Radio Amateur's Handbook are the further impacts of the war on the fields of higher frequencies. While basically the previous edition, certain additions have resulted from the slight rearrangement of the outermost ruffles on the curtains of censorship which have become the technical horizons of citizen radio.

Notable preparatory material that has been added is that on wave guides, cavity resonators, pot tanks, and butterfly circuits in the chapter on fundamentals. The section on vacuum tubes now includes compensation for low- and high-frequency deficiencies in amplifiers, cathode followers, grounded-grid operation, Franklin oscillator, vacuum-tube switches, pulse technic, inductive-output tubes, velocity modulation (velocity variation), Klystrons, and positive-grid oscillators.

Under antennas, we now find the Alford loop, bazooka balancer, and conical structures. To receivers have been added a complex crystal-filter set and a panoramic receiver.

The chapter on The War Emergency Radio Service has been substantially revised with much new equipment including receivers, transmitters, transceivers, and walki- and handie-talkie sets.

The measurements chapter has been expanded to include signal generators for amplitude- and frequency-modulated waves. Audio-frequency, phase-shift, and intermodulation measurements are now treated.

The increase of about thirty pages from the previous edition is misleading. A large number of the figures have been reduced in size and great care is evident in the mechanical preparation of the book to conserve every possible bit of space. Much more than thirty pages of material has been added.

In mid 1944, differences of many years standing between the communications and power engineers on some of the fundamental graphical symbols were compromised at a conference called by the American Standards Association. This agreement affects the communication engineer chiefly in that the capacitor symbol will have one of the parallel lines slightly curved. The *Handbook* is probably the first major revision of a radio text to adopt the new symbol. Every figure using a capacitor symbol, fixed or variable—meaning almost every figure in the book—has been redone to comply with the new standard. Once more the amateur leads the way!

Known for almost two decades for its up-to-date clear presentation of high- and higher-frequency radio fundamentals and practice, the *Handbook* continues to be the greatest compilation of radio information for your dollar.

Harold P. Westman
Electrical Communication
International Telephone and
Telegraph Corporation
New York, N. Y.

Alignment Charts—Construction and Use, by Maurice Kraitchik

Published (1944) by D. Van Nostrand Co., Inc., 250 Fourth Avenue, New York, N. Y. 91 pages+2-page index+vi pages. 48 illustrations. $6\frac{1}{2}\times9\frac{1}{2}$ inches. Price, $2.50.

The author defines an alignment chart as follows: An alignment chart for a function of three variables, $F(a, b, c)=0$, consists of an a scale, b scale, and c scale so constructed that any straight line connecting three points one on each scale determines a triple of values (a, b, c) satisfying the given function. This definition immediately suggests two problems: Given an alignment chart, in the sense of being given three curves to serve as basis curves for the (a), (b), and (c) scales, what functions can so be represented? Given a function, what are the best alignment charts, if any, available for the function? This book succeeds in presenting in a concise manner the practical solution to the above problems.

The first four chapters constitute an introduction covering a review of the mathematical terminology, an introduction to determinants, a short discussion of the broad field of nomographic charts (which the author defines as a diagram or combination of diagrams for the representation of mathematical laws), a review of graduated scales, and a short discussion of conversion scales. The fifth chapter describes a general background of the book showing how an equation may be disjuncted into a determinant equation in rectangular co-ordinates so that a nomographic chart can immediately be constructed on rectangular co-ordinate paper. The following three chapters discuss in turn the commonest and most practical nomographic charts, namely, equidistant parallel scales, parallel scales not equidistant, and a combination of two parallel and one curved scale. The various types of equations which can be so represented are clearly illustrated with profuse examples of substitution into the given formulas.

The ninth chapter of this book illustrates how the methods of alignment charts for three variables can be adapted to the construction of alignment charts for the solutions of functions involving more than three variables. The last section of the book contains a discussion of the choice among different types of representations (since very often more than one representation of an equation can be made), and a discussion of special charts.

The author makes no attempt to give an extended or theoretical study of the subject and he refers the reader to d'Ocagne's work "Traité de Nomographie" (Paris, 1921) for further information. The book is written concisely and to the point. It is well organized and numerous examples are given so that the methods expounded may be employed with a minimum of confusion by the reader.

Nathan Marchand
Federal Telephone and
Radio Laboratories
New York, N. Y.

Resistance Welding Control (Set of Seven Lesson Books and One Quiz Book)

Published (1944) by Westinghouse Electric and Manufacturing Company, 40 Wall Street, New York, N. Y. 85 pages. 324 illustrations. $7\frac{1}{2}\times5\frac{1}{4}$ inches. Price, $1.60 per set.

These eight booklets comprise a complete series of blackboard talks on the practical aspects of resistance welding control. The books are styled for use by practical workers in this field and for the use of others who are purchasing or setting up resistance welding equipment to do specific jobs. These booklets each contain ten (or more) pages of specific information accompanied by twenty-five or more illustrations or photographs, specifically selected to illustrate the details of this art.

Book 1 defines the terms of welding technology and illustrates the various types of welds that can be handled with this type of equipment. Book 2 entitled "Types of Resistance Welding Work," gives details as to the requirements of each class of work, and includes several excellent tables of values based on various types of metals and alloys that can be handled. Book 3 gives a description of the ignitron and the thyratron tubes, illustrating in a nontechnical manner their operating principles. Book 4 illustrates how the flow of current is started and stopped in resistance welding work, including details as to several of the circuits in use. Book 5 illustrates how the amplitude of the current is controlled in resistance welding. Book 6 gives more details as to electronic timing controls and Book 7 takes up the basic principles of the energy storage systems using systems of both types, the magnetic type of energy storage and the capacitor type of energy storage.

The last book of the series is a questionnaire giving a number of questions enabling the reader to test himself as to his knowledge of this article as it was outlined in the series of text.

Ralph R. Batcher
Caldwell-Clements, Inc.
New York, N. Y.

Report of the Secretary—1944

Membership

The total of 13,137 paid members at the end of 1944 represents a new high in Institute membership. This increase of 2058 paid members over the 1943 figure shows a gain of 18.6 per cent. The membership trend since the establishment of the Institute in 1912 is plotted in Fig. 1. Resignations were received from 21 members.

The proportion of the membership outside of the United States and its possessions reached its maximum in the period 1934–1938 when it varied between 23.2 and 24.2 per cent. The trend was downward from 1939 through 1943 as a result of the war. However, an interesting note is that the foreign members comprised 11.7 per cent of the total membership at the end of 1944 as compared with 10.7 per cent the previous year. This is due mainly to the large rise in membership in Canada and England which is included in the figure. Increases of 17.2 per cent in the domestic membership and 29.8 per cent in the foreign membership, despite wartime conditions, were shown at the end of 1944.

The number of members in the British Empire increased by 303 as compared with the addition of 191 members the previous year. The gain in England was largely responsible for the increase of 111 members in the European area. The South American membership increased by 55 members.

There was a marked increase in the number of applications submitted for Senior Member and Member grades during the year. The Admissions Committee considered 655 applications for election or transfer to those grades, of which 497 were approved.

There were 2721 new members elected to the Institute in 1944 which represents a slight decrease of 0.9 per cent in comparison with the previous year's elections.

The proportion of newly elected members having had some college training was 69 per cent as compared with 74 per cent in 1943. The proportion of those doing radio-engineering work decreased from 47 per cent in 1943 to 38 per cent in 1944. The sales and service personnel increased from 13 to 22 per cent. These analyses exclude Student members. It should be noted that, because of the secret nature of the war work a number of the newly elected members were performing, it was difficult to make an accurate analysis of their work.

During 1944, 2712 applications for admission were received, representing a loss of 3 per cent since 1943 when 2783 applications were received. However, there was a gain of 22 per cent in the number of applications for all elective grades received. The number of Student applications decreased by 36 per cent.

Total Applications Received

The effective work during the year of the Admissions Committee under Chairman G. T. Royden and the Membership Committee under Chairman E. D. Cook is reflected in the high membership figures at the end of 1944.

A large number of applications was received through the efforts of the Sections and the Institute office and many individual members.

Deaths

During 1944, the deaths of three Fellows, four Senior Members, 22 Associates, and two Students, whose names are listed below, were reported.

FELLOWS

Ballantine, Stuart (A'16–F'28)
Hill, Guy (M'13–F'15)
Thompson, B. J. (A'29–M'32–F'38)

SENIOR MEMBERS

Cose, J. H. (M'43–SM'43)
Guilfoyle, T. J. (M'35–SM'43)
Harper, A. E. (A'19–M'26–SM'43)
Winterbottom, W. A. (A'15–M'28–SM'43)

ASSOCIATES*

Davis, K. E. (A'43)
Elliott, D. A. (A'35)
Foil, W. P. (A'42)
Gibson, Robert (S'40–A'42)
Grimes, W. F. (VA'16)
Jinks, C. C. (VA'36)
Kaunitz, F. M. (VA'37)
Knowles, J. G. (VA'26)
Koenigsberg, Seymour (A'43)
McLain, W. W. (S'37–A'40)
Newbold, W. H. (A'28)
Novak, J. J. (VA'16)
Paleschuck, M. H. (S'41–A'42)
Parry, R. C. (VA'36)
Pensyl, D. S. (S'37–A'41)
Peterson, C. U. (VA'36)
Robb, J. D. (A'39)
Rosenthal, M. L. (A'44)
Slezskinsky, G. N. (A'35)
Watson, P. E. (VA'28)
White, M. W. (A'43)
Zwald, J. J. (VA'37)

STUDENTS

Mills, E. H. (S'42)
Wright, G. W. (S'43)

* Those designated "VA" were Voting Associates.

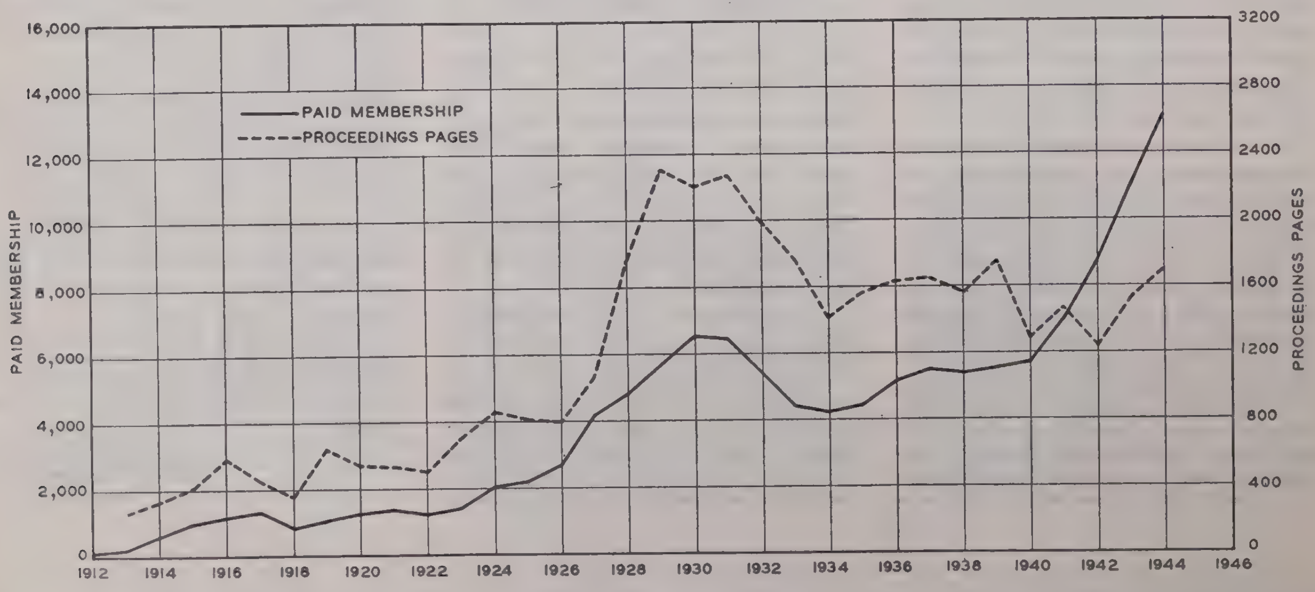


Fig. 1—The variation in paid membership is shown by the solid graph. The dotted line shows the number of pages of technical and editorial material in the PROCEEDINGS. Starting in 1939, a larger format was used. The number of pages indicated in the graph corresponds to the older format, and must be divided by 2.2 to give the corresponding number of pages of equal content in the present format.

Editorial Department

The twelve issues of the PROCEEDINGS OF THE I.R.E., published during the year 1944, contained 98 papers, the 125 authors of which included 7 with no business affiliation, and 118 from 32 colleges and organizations. Of these 125 authors, all but 21 were members of the Institute, and 3 of these 21 were previous members.

The PROCEEDINGS contained 774 numbered pages of editorial material plus 30 unnumbered pages, and 796 pages of advertising plus 36 advertising pages on covers.

Close co-operation with the National Electronics Conference will make it possible for the PROCEEDINGS to present in its pages many of the papers presented before that Conference in Chicago. One of this number was published in 1944, and many others were received, accepted, and scheduled for publication in 1945.

Illustrations with descriptive captions continued to be used on the front covers. Special emphasis was laid on Bond Drives. The June cover promoted the United States Fifth War Loan, and the October cover was devoted to the Seventh Canadian Victory Loan.

Towards the end of the year, it was decided to issue a YEARBOOK as soon as possible. Much thoughtful planning was done in this connection, although no actual work was started on this publication in 1944.

An appeal for a moderate increase in paper allocated to the PROCEEDINGS was made to the War Production Board on May 25, 1944. This appeal was granted on July 13. On October 27, an appeal was made for the proportionate continuance of this paper allocation for the year 1945. This appeal was denied on November 8.

Lightweight paper stock caused numerous printing difficulties in that the paper had a tendency to fly off the presses and cause trouble in handling. This resulted in a loss of paper and a surcharge for handling. The resulting printed page was far from satisfactory since the printed matter showed through. In the case of charts and diagrams, there was considerable confusion to the reader; in the case of advertisements, some dissatisfaction was evidenced by advertisers.

The Papers Procurement Committee, under the able and active guidance of Mr. Dorman D. Israel, was responsible for the obtaining for the PROCEEDINGS many papers which otherwise would not have been made available. This Committee was reorganized into 16 groups, each one under the capable leadership of an outstanding authority in his field. These groups, in turn, solicited manuscripts from recognized workers in their particular fields.

The Papers Committee continued under the thoughtful and effective direction of Dr. F. B. Llewellyn. Its duties involved the reading of the submitted manuscripts and the detailed and analytic criticism of them. The Board of Editors functioning in a judicial manner, studied, and co-ordinated the reports of the members of the Papers Committee. The conscientious work performed by the members of the Papers Committee and the Board of Editors is directly responsible for the high quality of the papers accepted and published in the PROCEEDINGS.

In spite of wartime restrictions, there was an adequate supply of excellent manuscripts submitted for publication. A decided trend was noticed in the emphasis laid on electronic and industrial engineering, broad communications problems, and analytical papers dealing with educational problems and professional engineering welfare.

In December, a new cover was introduced. This was imperative because of the growing trend in the PROCEEDINGS towards papers on electronics and electronic devices and a general enlargement over a long period of years of the fields covered by the PROCEEDINGS.

Because of the splendid co-operation of everyone concerned with the production of the PROCEEDINGS, it was possible, even under wartime conditions, to publish useful and constructive volumes. Sincere thanks should go to Dr. Alfred N. Goldsmith, who devoted fully a third of his time to PROCEEDINGS and Institute activities; who was ever on the alert for new trends; and whose sympathetic and helpful guidance was always an inspiration to those working with and for him; to Mr. Dorman D. Israel for his constructive and painstaking efforts on behalf of the Papers Procurement Committee; to Dr. Frederick B. Llewellyn for his able guidance as Chairman of the Papers Committee; to the membership of the Papers Procurement Committee, the Papers Committee, and the Board of Editors for their unfailing willingness to devote much time and energy to their duties for the Institute; and to the editorial staff attached to the Institute, Miss Helen M. Stote, associate editor, and Miss Winifred Carrière, assistant editor, for their enthusiastic

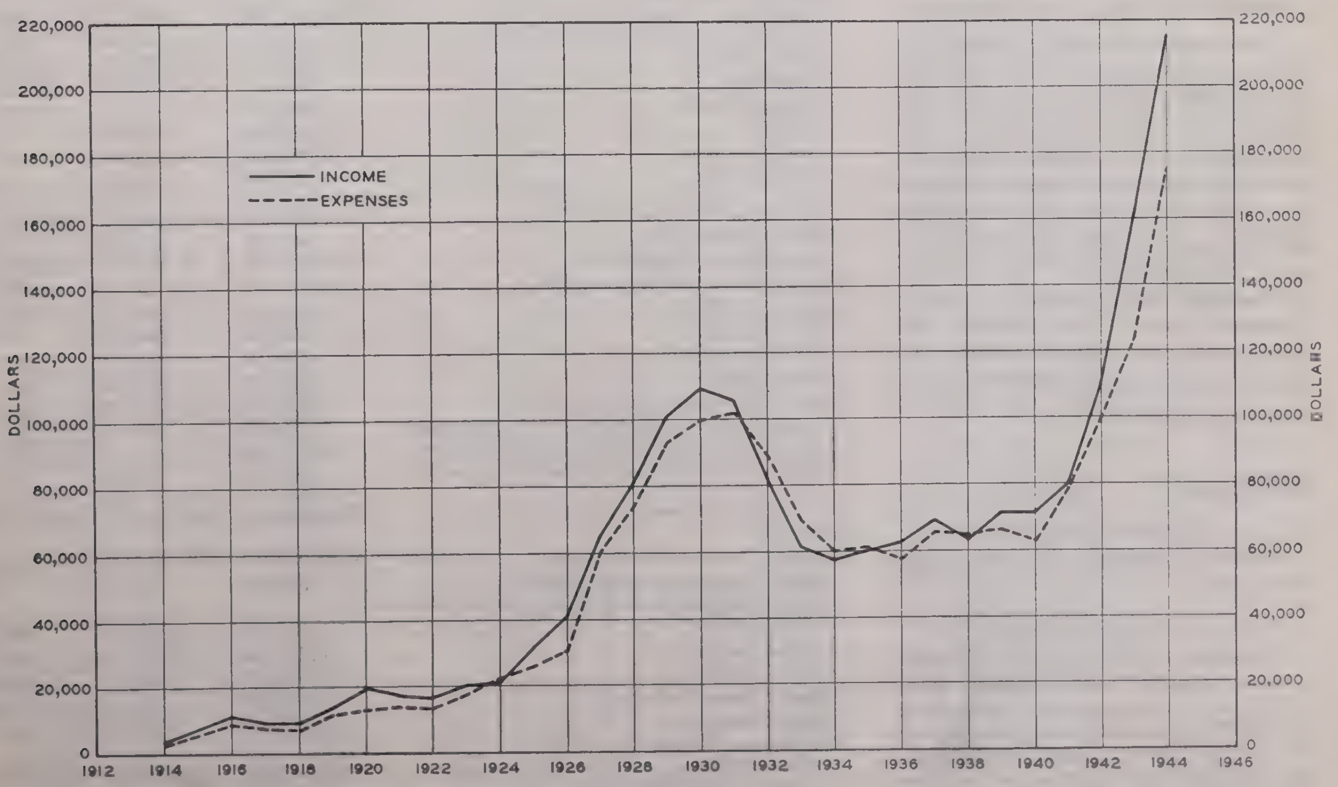


Fig. 2—Income and expenses are plotted for the life of the Institute.

cooperation and effective work in carrying out the wishes of the editorial groups. The George Banta Publishing Company, printer of the PROCEEDINGS, successfully carried out its assignments under unusually difficult wartime conditions involving shortages of manpower and materials.

Advertising

Advertising Manager W. C. Copp, and his efficient staff, produced a record volume of advertising.

Sections

The Sections Committee, under Chairman R. A. Heising, was very active throughout the year.

Several new Sections were established during the year, bringing the total to 33 Sections at the end of 1944. There were 278 Section meetings held during 1944, representing an increase of 32 per cent over the number held in 1943.

All Sections in operation during the entire year met the minimum requirements of 5 meetings and 25 members. The proportion of the membership in Section territories rose from 76 per cent in 1943 to 77 per cent in 1944. Numerically, the total membership in Sections rose from 8421 to 10,101 at the end of 1944.

During the year, President Turner visited the Boston, Chicago, Cincinnati, Connecticut Valley, Dayton, Philadelphia, Pittsburgh, Rochester, and St. Louis Sections.

Conventions and Conferences

The 1944 Winter Technical Meeting was held on January 28 and 29 in New York City and was considered to be one of the most successful of its kind held by the Institute, and Dr. B. E. Shackelford and his committeemen were complimented for their outstanding work in directing the affairs of the meeting. There were 22 technical papers presented. The banquet was attended by 808, while the total attendance at the two-day meeting was 1704.

The Rochester Fall Meeting was held on November 13 and 14 in Rochester, New York. During the two-day session, there were 12 technical papers presented. Some 300 persons attended the banquet and the total attendance was 707.

Meetings

Board of Directors

The Board of Directors held 12 meetings during 1944.

Executive Committee

Members of the Executive Committee carried unusually heavy burdens during 1944, due to the increasing burden of activities of the Institute, under wartime conditions. In addition to the Institute's officers on this Committee, the other members were Mr. E. F. Carter, Dr. F. B. Llewellyn, and Mr. H. A. Wheeler. Mr. Carter was responsible for the committees on Admissions, Membership, and Public Relations; Dr. Llewellyn, the activities of the Technical Committees; and Mr. Wheeler guided the activities covering Sections, Conventions, Meetings, and Advertising.

Thirteen meetings were held during the year.

Administrative Committees

Twenty-five meetings were held by the administrative committees during 1944.

Attention is called to the fact that, in addition to the meetings mentioned above, a large volume of work was accomplished through correspondence and the use of the telephone.

Special Committees

Realizing the urgent need for a home for the Institute and taking into consideration the reports of Chairman Heising of the Office Quarters Committee, which had been diligently searching for increased office space to house the present staff and provide adequate room for expansion, the Board of Directors appointed the Building-Fund Committee with Dr. Shackelford as Chairman and Mr. I. S. Coggeshall as Vice-Chairman to raise funds to be used for the purchase of a suitable building. Toward the end of the year, the Building Fund campaign with a goal of $500,000 was inaugurated.

Technical Committees

The technical committees held 27 meetings during the year in comparison with 10 in 1943. Correspondence played an important part in expediting the work of these committees when no meetings were held.

Summary of Meetings

The following table summarizes the meetings held during 1944.

Meetings Held During 1944

12 Board of Directors
13 Executive Committee
25 Administrative Committees
31 Special Committees
27 Technical Committees

108

Constitution and Laws

Chairman Heising of the Constitution and Laws Committee offered a number of proposed constitutional amendments for consideration of the membership. Those adopted involved a broadening of the power of the Board of Directors in organizing Institute activities, minor changes in language to

COMPARATIVE STATEMENT OF INCOME AND EXPENSES FOR THE YEARS ENDED DECEMBER 31, 1944, AND 1943

	1944	1943	Increase **Decrease**
INCOME			
Current Year's Dues			
Student	$ 6,451.00	$ 5,809.00	$ 642.00
Junior	—	341.00	**341.00**
Associate	55,175.25	43,052.25	12,123.00
Member	247.75	8,487.50	**8,239.75**
Senior Member	8,948.00	—	8,948.00
Fellow	1,870.00	1,760.00	110.00
Entrance Fee	5,999.00	4,654.00	1,345.00
Transfer Fee	258.00	164.00	94.00
TOTAL DUES INCOME	$ 78,949.00	$ 64,267.75	$14,681.25
Dues of Prior Years	493.80	416.30	77.50
Advertising in PROCEEDINGS	98,911.40	77,858.27	21,053.13
Subscriptions to PROCEEDINGS	15,122.15	12,123.37	2,998.78
Sale of Emblems	1,968.58	1,800.35	168.23
Sale of Reprints	1,730.11	998.20	731.91
Sale of Bound Volumes	480.50	376.75	103.75
Sale of Binders	1,865.81	1,064.02	801.79
Sale of Standardization Reports	1,023.56	652.59	370.97
Income from Investments—I.R.E. Securities	1,288.09	1,410.37	**122.28**
Income from Winter Technical Meeting	12,704.55	—	12,704.55
Miscellaneous (Radio Markets, Index, etc.)	106.82	64.75	42.07
TOTAL INCOME	$214,644.37	$161,032.72	$53,611.65
EXPENSES			
Cost of Printing PROCEEDINGS	$ 39,292.37	$ 33,085.90	$ 6,206.47
Cost of Standardization Reports	888.42	855.95	32.47
Cost of Miscellaneous Printing—Index, Radio Markets, etc.	1,950.62	2,526.98	**576.36**
Cost of Emblems	1,237.66	1,077.19	160.47
Cost of Reprints	1,436.67	827.21	609.46
Cost of Bound Volumes	63.88	132.47	**68.59**
Cost of Binders	1,274.86	926.49	348.37
Salaries and Wages			
General Office	35,422.41	24,266.07	11,156.34
Printing PROCEEDINGS	7,417.59	5,002.00	2,415.59
FORWARDED	$ 88,984.48	$ 68,700.26	$20,284.22

COMPARATIVE BALANCE SHEET DECEMBER 31, 1944, AND 1943

Assets	December 31, 1944	December 31, 1943	Increase **Decrease**
Current Assets			
Cash	$127,571.97	$ 77,319.24	$50,252.73
Accounts Receivable—Current			
Dues	82.36	103.76	**21.40**
Advertising	4,857.20	4,674.12	183.08
Reprints	81.03	45.00	36.03
Others—Sections, etc.	685.00	304.32	380.68
Inventories (As submitted by the Management)			
Proceedings	5,229.60	7,049.04	**1,819.44**
Bound Volumes	231.00	170.00	61.00
Binders	680.75	231.01	449.74
Emblems	1,360.14	693.66	666.48
Accrued Interest on Investments	15.62	57.29	**41.67**
Total Current Assets	$140,794.67	$ 90,647.44	$50,147.23
Investments—At Cost			
(Market Value—12/31/44—$43,905.11)	45,260.15	45,899.54	**639.39**
Morris Liebmann Memorial Fund Assets			
Investments (Market Value 12/31/44—$10,465.24)	10,140.55	10,012.45	128.10
Cash	1,079.48	778.00	301.48
Total Fund Assets	$ 11,220.03	$ 10,790.45	$ 429.58
Furniture and Fixtures after Reserve for Depreciation	4,995.74	5,229.86	**234.12**
Prepaid Expenses and Other Assets			
Unexpired Insurance	$ 68.93	$ 47.86	$ 21.07
Stationery Inventory—Estimated	200.00	200.00	—
Medal of Honor	—	50.50	50.50
Winter Technical Meeting Expense	1,074.59	287.81	786.78
Medallion Badges and Lapel Bars	577.22	667.44	**90.22**
Investment Service	210.78	123.75	87.03
Building-Fund Committee			
Rent—January, 1945	225.00	—	225.00
Utility Company Deposit	10.00	—	10.00
Rent Deposit	225.00	—	225.00
Total Prepaid Expenses and Other Assets	$ 2,591.52	$ 1,377.36	$ 1,214.16
Total Assets	$204,862.11	$153,944.65	$50,917.46

Liabilities and Surplus	December 31, 1944	December 31, 1943	Increase **Decrease**
Accounts Payable	$ 9,028.48	$ 7,723.52	$ 1,304.96
Accrued Salaries	305.70	104.29	201.41
Section Rebates	—	203.00	**203.00**
Advance Payments			
Dues	12,228.84	7,940.14	4,288.70
Subscriptions	7,374.77	4,279.94	3,094.83
Income Tax Withheld from Employees, Etc.	539.92	899.52	**359.60**
Total Liabilities	$ 29,477.71	$ 21,150.41	$ 8,327.30
Morris Liebmann Memorial Fund			
Investments	$ 10,140.55	$ 10,012.45	$ 128.10
Unexpended Income	1,079.48	778.00	301.48
Total Fund	$ 11,220.03	$ 10,790.45	$ 429.58
Deferred Income—Winter Technical Meeting	$ 2,404.50	$ —	$ 2,404.50
Surplus—Donated	$ 1,997.80	$ 1,997.80	$ —
Surplus—Earned			
Balance—January 1	$120,005.99	$ 83,713.15	$36,292.84
Add—Operating Profit for the years (Per Exhibit "B")	39,756.08	36,292.84	3,463.24
Total Earned Surplus	$159,762.07	$120,005.99	$39,756.08
Total Surplus and Liabilities	$204,862.11	$153,944.65	$50,917.46

make the Constitution conform to the charter, correction of a situation in the Institute office resulting from the previous regulations regarding time limits on arrival of petitions and ballots, and clarification of methods of voting on constitutional amendments. Several Bylaws amendments also were adopted.

Awards

The Medal of Honor for 1944 was presented to Haraden Pratt in recognition of his engineering contributions to the development of radio, of his work in the extension of communication facilities to distant lands, and of his constructive leadership in Institute affairs.

The Morris Liebmann Memorial Prize for 1944 was awarded to W. W. Hansen for his application of electromagnetic theory to radiation, antennas, resonators, and electron bunching, and for the development of practical equipment and measurement techniques in the microwave field.

The following 11 members of the Institute were transferred to the Fellow grade.

S. L. Bailey	Keith Henney
C. R. Burrows	D. O. North
M. G. Crosby	K. A. Norton
Harry Diamond	S. W. Seeley
C. B. Feldman	D. B. Sinclair

L. C. Young

Finances

Copies of the auditor's report for 1944 were distributed to the Board of Directors. The income and expenses for the life of the Institute are plotted in Fig. 2.

Headquarters Office

At the beginning of the year, there were 17 employees on the staff in addition to the Advertising Manager and his staff who were continued on a contractual basis. In May, Miss Elizabeth Lehmann was engaged as Office Manager, and has carried out her assignments with loyalty and industry.

It was necessary for the staff to carry a considerable amount of overtime work. Accordingly, the number of employees was gradually increased until there was a total of 24 at the end of 1944. One of these employees was on a part-time basis, two were temporary employees, and the remaining 21 were permanent full-time employees.

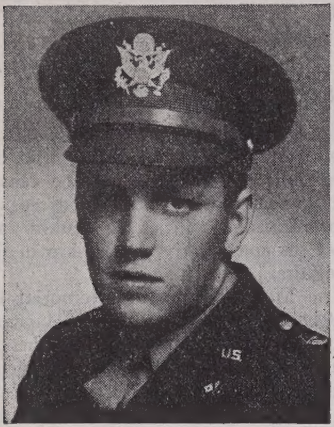
Late in the year, three new positions were established by the Board of Directors; namely, Executive Secretary, Technical Editor, and Technical Secretary. These additions to the executive staff were intended to broaden the future activities of the Institute, to permit the expansion of the publications program, and to provide services required by the increase in membership. It was decided to fill these positions as soon as suitable personnel could be obtained.

Respectfully submitted

Haraden Pratt

Haraden Pratt
Secretary

Contributors



Robert M. Barrett

Robert M. Barrett (S'41–A'43) was born on March 3, 1920, in Farmington, Utah. He received the B.S. degree in electrical engineering from the University of California in 1942.

Since 1942, he has been on active duty with the Army Air Forces as a radar engineering officer.

Captain Barrett is now stationed at Morrison Field, Florida, where he is in charge of installation and maintenance of airborne electronic equipment.

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Willard R. Clark (A'36–M'45) was born on May 23, 1911, at Medway, Massachusetts, and has been an amateur radio operator since 1927. He was graduated from Massachusetts Radio and Telegraph School of Boston in 1929, and served an enlistment in the Signal Corps, United States Army, from 1930 to 1933. From 1934 to 1939 he was associated with Tropical Radio and Telegraph Company, Valpey Crystal Corporation, Pan American Airways System, and Eastern Air Lines, Inc. Since 1939 he has been employed by the Signal Corps

Willard R. Clark

Ground Signal Agency and its predecessor, the Signal Corps Laboratories, at present being a member of the engineering staff of the Coles Signal Laboratory. In 1944 the Commanding General of the Army Service Forces awarded Mr. Clark the War Department Emblem for Meritorious Civilian Service, with a citation for outstanding work in the development of frequency-modulation equipment and in organizing and supervising development of radio-relay communication equipment for the United States Army. He is a member of the Veteran Wireless Operators Association and the American Radio Relay League.

❖

Beverly Dudley

Beverly Dudley (J'24–A'27–M'43–SM '43) was born on April 2, 1906, at Chicago, Illinois. He attended Armour Institute from 1926 to 1928. In 1935 he received the B.S. degree from Massachusetts Institute of Technology, and from 1935 to 1939 he did graduate work in electrical engineering and physics at Columbia University.

Mr. Dudley was assistant technical editor of *QST* at the American Radio Relay League from 1929 to 1930, and assistant secretary of The Institute of Radio Engineers from 1930 to 1932. He was engaged in technical editorial work at the General Radio Company during the summer of 1934, and in experimental and factory production, test, and specifications on cathode-ray tubes and metal receiving tubes at the RCA Manufacturing Company during 1935 and 1936. In 1936 he became associated with the McGraw-Hill Publishing Company, in New York City, where he remained until 1943, first as associate editor and later as managing editor of *Electronics*.

From 1941 to 1943 Mr. Dudley taught classes in radio communication at the Newark College of Engineering, and from 1943 to 1945 he was located in Chicago, as Western Editor of *Electronics*. During his sojourn in Chicago, he took an active part in the formation and management of the National

W. W. Hansen

❖

Electronics Conference. He is at present editor of the *Technology Review* of Massachusetts Institute of Technology, while retaining his connection with the McGraw-Hill Book Company as consulting editor for the radio communication series originated in 1942.

❖

W. W. Hansen (A'39) was born in 1909 at Fresno, California. He received the A.B. degree in 1929 and the Ph.D. degree in 1932, from Stanford University. Dr. Hansen was an instructor in physics at Stanford University from 1930 to 1932; National Research Fellow from 1933 to 1934; and successively assistant, associate, and full professor at Stanford University until 1940, when he took leave to go to the Sperry Gyroscope Company as research engineer.

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Andrew F. Inglis (A'44) was born at Van, Michigan, on March 17, 1920. He received the B.S. degree in physics from Haverford College in 1941, and spent the following

Andrew F. Inglis

Martin V. Kiebert, Jr.

year in graduate study in electronics, at the University of Chicago. During the summers of 1940 and 1941, Mr. Inglis was employed by the Eastman Kodak Company, and in the summer of 1942 he was instructor of electronics at the University of Chicago. Following this, he was engaged in the development of radar equipment for the radio division of the Naval Research Laboratory, and in 1943, entered the United States Naval Reserve. He is at present instructor at the Naval Training School (Pre-radar), Bowdoin College, Brunswick, Maine. Mr. Inglis is a member of Phi Beta Kappa.

❖

Martin V. Kiebert, Jr. (A'31–M'38–SM'43) was born on Nov. 27, 1908, at Wallace, Idaho. He attended the University of Idaho from 1928 to 1931, and Reed College, Portland, Oregon in 1933 and 1934, majoring in electrical engineering and physics. In 1929 he was the recipient of the Idaho Edison Scholarship Award. From 1934 to 1937 he was chief engineer at KIRO, Seattle, Washington. In 1937 Mr. Kiebert became radio inspector for the Federal Communications Commission at Seattle, and in 1938 he was transferred to Washington, D. C., where he was associate engineer in the broadcast division. During 1939 he became affiliated with Jansky and Bailey, Washington, D. C., as a consulting radio engineer. In 1941 he became a consultant with McNary and Chambers, Washington, D. C. Mr. Kiebert entered the United States Naval Reserve in 1941. In 1942 and 1943 he was senior instructor in the Naval Training School (Pre-radar), Bowdoin College, Brunswick, Maine. In December, 1943, he was transferred to the radio and electrical branch of the Bureau of Aeronautics, United States Navy Department, Washington, D. C. He is stationed there at present with the rank of Lieutenant Commander.

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O. C. Lundstrom

O. C. Lundstrom (S'42) was born at Morristown, South Dakota, on September 12, 1917. He was graduated from the University of California in 1941 with the B.S. degree in electrical engineering. From 1942 to 1944 he was a graduate student and acting instructor at Stanford University, from which he received the A.M. and E.E. degrees in electrical engineering. Since 1944 Mr. Lundstrom has been employed by the Sperry Gyroscope Company as an assistant project engineer. He is a member of Tau Beta Pi, Eta Kappa Nu, and Sigma Xi.

❖

W. R. MacLean

William R. MacLean (A'42) was born on July 14, 1908 at Marinette, Wisconsin. He became interested in radio in grade school and operated a spark-coil crystal-detector station in 1921. Later he operated two licensed amateur stations while in high school, and a third at Massachusetts Institute of Technology where he received the B.Sc. degree in electrical engineering in 1929. For the following year he worked in the Bell Telephone Laboratories. Thereafter, during the Weimar republic, he studied physics a semester each at the Universities of Munich and Berlin. This was followed by most of a third semester at the Sorbonne. He did actuarial work from 1932 to 1937. Mr. MacLean returned to electrical engineering in civil service from 1937 to 1941, and then went to the Polytechnic Institute of Brooklyn where he received the M.E.E. degree in 1942 and is now employed as a research associate. He is a member of Sigma Xi and of the Acoustical Society of America.

❖

William S. Marks, Jr.

William S. Marks, Jr. (A'44–SM'44) was born in Nashville, Tennessee, on March 18, 1900. He received the B.S. degree in electrical engineering from the Louisiana State University in 1929, and did post-graduate work at Rutgers University.

He served in World War I as radioman in the United States Naval Reserve after graduating from the Naval Radio School at Harvard University. He was a commercial radio operator for Marconi Wireless and RCA from 1919 to 1925, and in 1929 became associated with the radio engineering department of the General Electric Company in Schenectady, N. Y. In 1930 he accepted an appointment as radio engineer with the Signal Corps Laboratories at Fort Monmouth, New Jersey, and became chief engineer of the vehicular radio branch. Mr. Marks was associated with the original development of Radar in 1936 and 1937, and pioneered in the development of mobile frequency-modulation equipment for the Army.

In 1942 he accepted a commission as Major in the Signal Corps, and was assigned as officer in charge of the radio communication branch, at Coles Signal Laboratory. In 1944 he served as technical advisor to Major General Roger B. Colton, chief of the engineering and technical service in the Office of the Chief Signal Officer, on a tour of Signal Corps installations in the Italian, European, and North African theater of operations. He received the rank of Lieutenant Colonel in 1944 and he is now assigned to the engineering staff, headquarters, Signal Corps Ground Signal Agency, at Bradley Beach, New Jersey.

He is a member of the Veteran Wireless Operators' Association.

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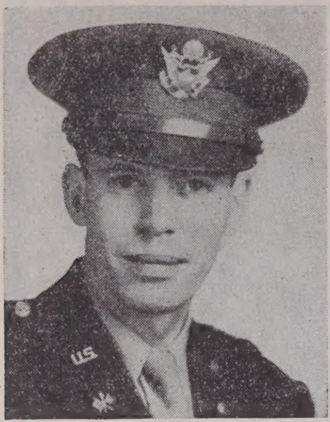
Oliver D. Perkins (A'36–M'38–SM'43) was born at Milwaukie, Oregon, on August 11, 1910. He received the B.S. degree in electrical engineering from Oregon State College in 1931, and the M.S. degree in physics from the same institution in 1933.

During 1928 and 1929, he served as a shipboard radio operator for the Alaska Steamship Company; and from 1931 to 1936 was a member of the technical staffs of



Lorstan Studios

Oliver D. Perkins

KOAC and KOIN, respectively. Mr. Perkins entered civil service as a radio engineer for the Signal Corps in 1937, serving in Washington, D. C., Fort Sam Houston, Texas, and Fort Shafter, Hawaii. He was transferred to the Signal Corps Laboratories at Fort Monmouth, New Jersey, in 1940.

In 1942 Mr. Perkins entered active military duty as a First Lieutenant, receiving the rank of Captain later in the same year. In 1943, with a group of civilian Signal Corps engineers in the North African Theater of Operations, he developed and supervised the first applications of radio-relay communication systems and radio teletype in tactical operations by the allied military forces, utilizing commercial frequency-modulation radio equipment. In the following year he was associated with the initial planning for use of radio-relay communication systems across the English Channel in the invasion of France, and since that time has been active in further development of radio-relay systems and integrated wire and radio facilities. He is at present a member of the engineering staff Headquarters, Signal Corps Ground Signal Agency.

Captain Perkins is a registered professional engineer, and a member of Eta Kappa Nu, Sigma Pi Sigma, and the American Radio Relay League.

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Cecil C. Pine (A '43) was born on February 12, 1910, in Castle Rock, Colorado. His education in radio engineering was obtained through home study courses. He also attended classes in engineering at the University of Washington. He has been active in the radio field since 1929, during which time he maintained his own amateur station. For the past several years he has made a special study of radio direction finding, and at present is employed by the Sperry Gyroscope Company, as engineer in this field. Previous to this he was employed by the Alaska sector of Pan American Airways, at Seattle, Washington.

Cecil C. Pine

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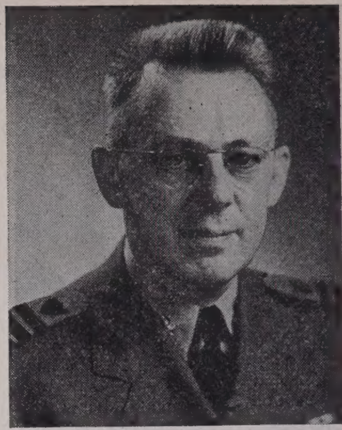
E. M. Webster (A'30–M'38–SM'43–F'44) was born in Washington, D. C. in 1889 and was graduated from the United States Coast Guard Academy in 1912, with an appointment as Ensign.



E. M. Webster

He saw service during World War I, and in 1923 was made Chief Communications Officer of the Coast Guard. In 1934 he was retired because of disability and joined the staff of the Federal Communications Commission as assistant chief engineer. Recalled to active duty in the Coast Guard in 1942, he was reassigned to his former duty as Chief Communications Officer, with the rank of Captain.

He has been active for many years in coordinating communication activities within the government. His association with the Interdepartment Radio Advisory Committee dates from 1923, during the first year of its existence. As a government representative, he has attended many international communications conferences, including the London Safety of Life at Sea Conference in 1929; telecommunications conventions at Washington in 1927, Madrid in 1932, and Cairo in 1938; the International Technical Consulting Committee on Radio Communication at Copenhagen, in 1931; and the International Telegraph Conferences at Paris, in 1925, and Brussels, in 1928.